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BEAN ANTHRACNOSE

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BEAN ANTHRACNOSE

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MORTIER F. BARRUS

THE HOST

Next to the potato and the sweet potato, the bean (considered as a vegetable) is the most important crop grown in this country. Not only are beans grown in practically every home garden, but they are of great commercial importance also. The United States Census Bureau (1913a) reports the production of dry edible beans grown for commercial purposes in this country during 1909 as 11,251,160 bushels, or more than double that of 1899, representing a value of $21,771,482. The Monthly Crop Report of the United States Department of Agriculture (1917: 133) estimates the production for 1916 as 12,029,000 bushels; for 1917 it was 18,129,000 bushels, the culture of beans having been stimulated by the demand and by the high prices paid as a result of the war. Since the war there has been a marked reduction in area in the States having a high bean production. Dry beans are a staple crop in New York, Michigan, Colorado, New Mexico, California, and several other States, while string beans are grown extensively in many parts of the country as a truck crop. In northern New York, in Michigan, Colorado, and California, and in southern Canada, the production of garden and field beans for seed has developed into a large and profitable industry. Large areas also are devoted to the production of snap beans for canning.

Prior to 1899, New York was the leading State in the production of dry edible beans, in 1879 producing 42.4 per cent of the total crop in the United States and in 1889 producing 35.1 per cent. In 1909, however, it produced only about 15 per cent of the total crop (U. S. Census Bureau, 1913a). While production has greatly increased in the other large bean-producing States (table 1), New York has lagged behind, although it was stirred on somewhat during 1917 and 1918.[1] Low yields resulting from disease and from poor weather conditions inevitably resulted in reduced acreage for 1919.

[1] Data for 1879 and 1889 were obtained from the Eleventh Census; for 1899 and 1909, from the Thirteenth Census; for 1914, from the Monthly Crop Report for 1916; for 1915, 1916, and 1917, from the Monthly Crop Report for 1917; for 1918, from the Monthly Crop Report for 1918; for 1919, from the Monthly Crop Reporter for 1919; for 1920, from the Monthly Crop Reporter for 1920. These references are given under *Literature Cited*, page 199.

TABLE 1. ACREAGE AND PRODUCTION (IN BUSHELS) SINCE 1879, OF DRY EDIBLE BEANS IN THE FIVE LARGEST BEAN-PRODUCING STATES AND IN THE UNITED STATES

Year		New York	Michigan	California	Colorado	New Mexico	United States
1879	Production...	1,303,444	167,658	378,971	.....	16,168	3,075,050
1889	Production...	1,111,510	434,014	713,480	7,265	7,843	3,163,554
1899	Acreage.....	129,298	167,025	45,461	2,406	17,417	453,841
	Production...	1,360,445	1,806,413	658,515	28,570	36,022	5,064,490
1909	Acreage.....	115,698	403,669	157,987	5,040	20,766	802,991
	Production...	1,681,506	5,282,511	3,328,218	53,926	85,795	11,251,160
1914	Acreage.....	118,000	490,000	215,000	20,000	32,000	.....
	Production...	1,650,000	5,488,000	3,875,000	300,000	272,000	.....
1915	Acreage.....	130,000	506,000	225,000	21,000	46,000	.....
	Production...	1,495,000	4,250,000	3,868,000	340,000	368,000	.....
1916	Acreage.....	190,000	470,000	340,000	38,000	64,000	1,244,000
	Production...	1,140,000	3,102,000	5,576,000	424,000	425,000	12,029,000
1917	Acreage.....	210,000	639,000	558,000	193,000	213,000	2,117,200
	Production...	1,575,000	3,514,000	8,035,000	1,467,000	958,000	18,129,000
1918	Acreage.....	200,000	543,000	592,000	252,000	149,000	.....
	Production...	1,660,000	4,887,000	8,880,000	1,638,000	596,000	.....
1919	Acreage.....	90,000	300,000	400,000	69,000	123,000	.....
	Production...	1,305,000	4,140,000	5,000,000	448,000	922,000	.....
1920	Acreage.....	90,000	275,000	285,000	63,000	121,000	.....
	Production...	1,260,000	3,575,000	2,850,000	504,000	811,000	.....

The figures in table 2, taken from statistics compiled by order of the New York State Food Commission (1919), give the acreage and production during 1917 of important bean-growing counties in the State and show the location of the bean area. A larger yield to the acre was obtained by some of the other counties which planted a smaller acreage.

TABLE 2. ACREAGE AND PRODUCTION OF FIELD BEANS IN THE TEN LARGEST-PRODUCING COUNTIES OF NEW YORK STATE IN 1917

County	Acreage	Production (bushels)
Livingston	37,010	325,245
Wyoming	23,146	200,949
Genesee	18,835	101,158
Ontario	13,884	82,353
Wayne	12,615	86,105
Monroe	11,076	42,751
Orleans	9,640	38,561
Erie	9,235	46,547
Yates	9,007	70,442
Schuyler	8,164	59,650
New York State	218,742	1,477,061

New York ranks first of all the States in the amount and value of canned string beans, the United States Census Bureau (1913b) reporting 452,634 cases having a value of $839,135, or more than half the total value for the entire country. It is assumed that nearly all string beans canned in the States were grown within its territory.

It is thus seen that the bean industry in New York and in the country at large is an important one, and well worthy any attention that may be given to it by the Federal Government and by the various experiment stations.

The common bean (*Phaseolus vulgaris* L.) becomes affected at times by various diseases, among which the bean anthracnose is an important one in New York State. Bacterial blight also occurs frequently on the common bean and on the lima bean (*P. lunatus* L.), and was severe in 1916 and 1917. Root rots — especially the one caused by *Fusarium Martii phaseoli*, though black root rot, caused by *Thielavia basicola* Zopf., should be mentioned also — are causing considerable loss in restricted localities and may be more prevalent than is generally known. Rhizoctonia stem canker and pod spot, caused by *Corticium vagum* B. & C., has been reported from a few places as being serious and is known to have a general distribution. Bean rust, caused by *Uromyces appendiculatus* (Pers.) Lév., occurs occasionally, but does little damage in this State though it is severe at times in the South and the West. Brown rot, caused by *Sclerotinia libertiana* Fuckel, is destructive only during periods of extended rains and warm weather, and then only on vines so bushy that they do not permit good aëration. The leaf spot caused by *Phyllosticta* sp. is uncommon in the State, while leaf spot caused by *Isariopsis griseola* Sacc. has not been reported here.

In addition to the parasitic diseases just mentioned, mosaic, supposed to be due to a filterable virus, should certainly be included because of its general prevalence in the State and its apparently serious effect.

The writer has devoted more or less of his time for the past ten years to the study of the anthracnose disease and the manner of its control. In the following pages he presents his opinions and those of others in regard to the disease, and records the results of his experiments.

THE DISEASE

ECONOMIC ASPECTS

Name, history, and geographical distribution

The name *bean anthracnose*, generally applied by American, English, French, Italian, and other pathologists to the disease under consideration, was apparently first used in this connection by Scribner (1888), although the name *anthracnose* was used earlier to designate the grape disease caused by *Gloeosporium ampelophagum* Sacc. The terms *pod spot*, or *canker*, and *leaf spot* are sometimes applied to the disease as it occurs on these respective parts of the plant; while not uncommonly the terms *rust* and *blight*, and rarely *scab*, are erroneously used by laymen. Frank (1883 b) called the disease *Fleckenkrankheit*, and the names *Brennerflecken*, *Brennerfleckenkrankheit*, *Brennfleckenkrankheit*, and *Schwarzfleckenkrankheit* have been used by German writers. In Holland, Schenk (1917) speaks of the disease as *Vlekziekte*, and in Denmark it is called *Bonnesyge* by Lind (1910).

The disease was first definitely described by Saccardo (1878), who reported its discovery by Lindemuth in the fruit and vegetable garden of the Agricultural Institute of Poppelsdorf, at Bonn, in August, 1875. Anthracnose spots are present, however, on specimens of bean pods distributed by Desmazières (1843 b) under the name *Septoria leguminum* Nob. Berkeley (1880) reports the disease on kidney beans from Bedford, England, ascribing it to Ascochyta. Saccardo (1881) shows a good colored reproduction of a pod affected with anthracnose, and drawings of the fructifications of the fungus. The label indicates that the fungus was collected at Padua in June, 1875, on *Phaseolus vulgaris*. Frank (1883 b) states that Lindemuth reported to him the occurrence of the disease in 1875 on the red-mottled Zucker-Stangenbrechbohnen, and a few years later on numerous other varieties grown in the same vicinity. Frank himself says the disease occurred in other parts of Germany in 1881 and in various localities in 1882, it being especially severe the latter year. He gives an excellent account of the disease and its cause in the article cited. Saccardo (1884) mentions the disease as being common and injurious in Germany, Italy, France, England, and North America. Richon (1889) records its presence in the Marne district of France.

Ellis and Everhart (1885:111) report Dr. Farlow's observations of the common occurrence of this fungus on beans in the Cambridge (Massachusetts) market since 1882. From the Plant Disease Bulletin issued by the Plant Disease Survey of the United States Plant Industry Bureau (1918:254), it appears that the disease was reported from Pennsylvania, Maryland, and Louisiana in 1887; from Michigan in 1889; and from New York and Ohio in 1890. Scribner (1888:361), after speaking of its distribution in Europe, says that specimens have been received from Maine, Massachusetts, Wisconsin, Pennsylvania, Louisiana, and the District of Columbia.

Since then the disease has been reported from a number of places in Germany, Italy, England, and the United States. Reports of its existence — some recording only its presence and others its prevalence and destructiveness — have been recorded from Norway (Schoyen, 1901), Sweden (Eriksson, 1889), Denmark (Lind, 1910), Russia (Jaczewski, 1912), Tyrol (Bubák and Kabát, 1904), Belgium (Marchal, 1907), Holland (Sprenger, 1918), Ireland (Schoebotham, 1909), Japan (Ideta, 1911), Formosa (Fujikuro, 1914), India (Butler, 1918), Transvaal (Pole-Evans, 1907), Australia (Cooke, 1892), New Zealand (Kirk, 1905), Argentina (Spegazzini, 1899), Brazil (Puttemans, 1901), Cuba (Cook and Horne, 1908), Alaska (Anderson, 1916), and Canada (Craig, 1893).

From the bulletin issued by the Plant Disease Survey (U. S. Plant Industry Bureau, 1918) and from the earlier survey reports by Orton and by Orton and Ames (1904–1909), as well as from the bulletins and reports of the various experiment stations in this country, it appears that the disease has occurred at one time or another in every State in the Union except South Dakota, Wyoming, and Nevada. Doubtless it has occurred in these three States also but has not been reported.

It is thus seen that the disease is world-wide in its distribution, occurring in nearly every place where beans are grown. The climatic condition of a country or a region has much to do with the development of the disease, so that in some of the countries where it has been reported it is of no importance and in others it becomes a serious pest. While it has been reported from Alaska, it cannot be enphytotic there, as seed of *Phaseolus vulgaris* will not mature in that latitude; but the summer climate of Alaska is not unfavorable for the development of the fungus when introduced in imported seed affected by it.

Economic importance

While bean anthracnose can be found on some plants year after year, it is only during certain periods most favorable for its development that it becomes widespread and causes serious loss. Such epiphytotics are coincident with or closely follow periods of rather abundant rainfall during the growing season, and often recur in three or more successive years. Frank (1883 b: 512), as already noted, reports such an epiphytotic in Germany in 1882, Querner (1908) reports one in 1908, and Fischer (1919: 246) reports epiphytotics in 1915 and 1916. Voglino (1892) reports a complete destruction of the crop in 1891 in several localities in Italy.

Beach (1892: 308) reports a heavy loss in many sections of New York in 1891. Halsted (1893–1901) reports the disease as common from 1892 to 1897, after which it was an unimportant factor in his experiments. Whetzel (1908: 436) reports the disease as widespread in New York in 1906. Then followed five years during which the loss in most sections of the State was negligible. Late in the season of 1911, the disease was observed or reported from many fields, and in 1912 it was again severe. The following year there was very little anthracnose to be found except in restricted areas, but it was present to a destructive degree in 1914 and 1915, the loss during the latter year ranging from 30 to 100 per cent of the crop except in a few cases where resistant varieties were grown. During 1916 the damage done in this State was slight, but the disease appeared again from 1917 to 1919, the losses in these years, however, being much less than in earlier years.

A study of the table given in the Plant Disease Survey bulletin (page 254 of the reference already cited) shows that bean anthracnose was generally severe in the eastern United States from 1906 to 1908, from 1914 to 1915, and again in 1917. Individual reports of its severity are recorded in other years. In Maine and New Hampshire it is reported as causing considerable loss nearly every year, while in Western States it rarely does any damage although it may be present.

Figures are not obtainable to show the exact loss from this disease, but in epiphytotic years it is very large, amounting in individual cases to 100 per cent. Muncie (1917: 7) estimates a loss in Michigan of $1,500,000 in 1914 and of about $3,000,000 in 1915, while the loss in New York in 1915 probably amounted to $700,000 or more. The Plant Disease Survey

bulletin (page 13 of reference cited) gives the loss during 1917 for New York as 5 per cent, or 83,000 bushels, and for the United States as 1.76 per cent, or 363,000 bushels.

The losses from bean anthracnose are due to poor germination of affected seed, to destruction of affected seedlings, to low yield of affected plants, and to decreased value of the product. The principal loss in the production of green beans is due to the spotting of the pods, which renders them unsalable as snap beans and unfit for canning. Southern-grown beans, apparently healthy when shipped, frequently reach northern markets in a badly spotted condition, and if the disease is common in the field, pods kept over night after picking are likely to be rusted the next morning. The lesion may extend through the pod to the seed, discoloring it. The value of dry seed thus affected is lessened, and the buyer usually deducts a certain percentage, the "pick," from the total weight to allow for this depreciation. A poor stand often results from the planting of spotted seeds, many of which fail to germinate, and this result is augmented by the destruction of seedlings subsequently affected. Plants that have survived the early attack may give an inferior yield due to interrupted growth, although the pods themselves may not become spotted.

SYMPTOMATIC ASPECTS

While the appearance of anthracnose on the various parts of the bean plant has been described accurately by several investigators, a description is included here of its appearance as observed on different varieties of beans under different conditions and at different stages of maturity.

On the seed

The seed of the bean may be discolored by anthracnose, blight, rhizoctoniose, and brown rot, and by various mold-producing fungi. The appearance most characteristic of anthracnose (Plate IV) is the decided blackening of the affected parts. Usually the blackened area has a tawny brown or tan-colored[2] border, or the entire diseased area may consist of the latter color. Specimens are common in which the color of the spot on the seed is lighter, varying from drab to snuff brown or saccardo umber. The larger spots usually have a vinaceous buff to avellaneous-colored,

[2] The colors as given correspond to those given in Ridgway's *Color Standards and Nomenclature*, and, while characteristic, there is considerable variation from them.

often raised, center, which sometimes splits open disclosing the affected cotyledon. The spots may occur on any part of the seed coat, and may appear as a small black or brown speck or involve more than half the surface. In badly diseased seeds the lesion extends through the cotyledon and may even affect the embryo, but in many cases the cotyledon is but slightly or not at all discolored.

On the seedlings

Seedlings from badly diseased seed show blackened cankers on the cotyledons (fig. 10), in which, under moist conditions, small flesh-colored masses appear scattered over the surface of the lesions. The stem may become affected along its entire length, but usually it is affected only below the point of the attachment of the cotyledons. The first indication of a lesion is the appearance of brown specks in the epidermis. Later there appears a browning of the tissues lengthwise of the stem and below the epidermis. Still later, small pits appear along the affected area. Occasionally these cankers become so deep or so numerous that the stem is unable to support the parts above.

On the leaves

The leaves (figs. 10 and 11) not infrequently become badly affected. The lesions appear on the veins, usually on the underside of the leaf. These lesions have practically the same appearance as those on the stem. The tissues on each side of an infected vein and beyond it may wither and die. A considerable area of a leaf may become affected in this manner, giving it somewhat the appearance of blight. Usually only a small part of the leaf tissue is killed, and such places appear on the upper side as angular, elongated, dead areas, which sometimes become torn, giving the leaf a ragged appearance. The petiole may become so badly affected that it cannot support the leaf blade.

On the roots and other parts

The roots of plants growing in the soil are rarely if ever affected; but on seeds sprouted in a moist chamber, where the young roots are exposed, lesions similar to those on the stem may be produced by artificial inoculation. Muncie (1914: 4) mentions a rotting of the root due primarily to the anthracnose and blight organisms followed by secondary rot-producers

FIG. 10. ANTHRACNOSE ON YOUNG BEAN PLANT SHOWING LESIONS ON JUVENILE LEAVES AND ON STEM
(Photographed by H. H. Whetzel)

FIG. 11. ANTHRACNOSE ON BEAN LEAVES

Lesions on the veins cause death of the mesophyll about them, and show as brown dead spots or irregular areas on the upper surface of the leaves

The other parts of older plants may become diseased, and lesions similar to those already described may appear on the branches of the plant and on the pedicels, the sepals, and the bracts of the inflorescence. These parts of plants grown out-of-doors, however, become affected only during protracted periods of weather favorable for the organism.

On the pods

It is on the pods that the disease assumes its most striking appearance (Plate V). The first evidence of it there is the occurrence of tiny brown specks in the epidermis. These may be rufous or ferruginous, slightly elongated areas extending at an angle to the long axis of the pod. These specks enlarge to spots which become black at the center, with a vinaceous-rufous to hazel-colored border of varying width. These

black spots with colored borders are characteristic of anthracnose. The cankers range in size from a mere speck to spots one centimeter in diameter or even larger. By the union of several large cankers, a broad lesion is often formed which may extend from one end of the pod to the other. A canker may extend through the endocarp and even to the seed, particularly if infection takes place early, in which case the pod sometimes fails to develop and becomes shriveled and dried. Cankers resulting from infections that occurred during the later growth of the pod seldom extend below the endocarp. As the pod matures, the lesion is marked at the edge of a canker by a slightly raised, black ring with a cinnamon-rufous to chestnut-colored border. The center of the spot is then somewhat light buff in color. Flesh-colored spore masses on the surface of a young canker dry down to gray, brown, or even black granulations or to small pimples.

The appearance of the disease on the pods of the different varieties is very similar. The lesions on Blue Pod Butter, a variety producing dark blue-purple pods, are snuff brown instead of black in color; otherwise they are similar to those on other varieties. On a number of picked pods that had been left in a basket and were somewhat wilted, and in other cases in which inoculations were made, lesions one centimeter or more in diameter appeared which were light brown in color and marked by a slight depression. If the spores had not been present one would hardly have believed the lesions to be anthracnose, particularly as the typical lesions were present also on some of the pods. In some instances these unusual-appearing lesions later assumed the more characteristic appearance. Lochhead (1903) mentions the presence of a pink rot (*Cephalothecium roseum*) in anthracnose spots on bean pods, and at Ithaca this fungus has been found often in such lesions.

Blight lesions (Plate VI) on the pods may sometimes be confused with anthracnose. The blight lesion consists of an area having a water-soaked appearance extending along the dorsal suture, or of spots of a similar nature and of various diameters appearing on the sides of a pod. Often a pod may have many such discolored spots, these having originated from insect bites or punctures. The spots usually have an ochraceous-tawny center with a border of a cinnamon-rufous color, and commonly, as the pod matures, the entire lesion turns to hazel or to cinnamon brown with a more highly-colored margin. It may be distinguished from anthracnose by the absence of any dark color,[3] by the shape of the lesions which

[3] A saprophytic Alternaria may occur on blighted leaves and pods and give a blackened color to the lesion.

are usually more extensive and more irregular in outline than those of anthracnose, and by the absence of spore masses.

Rhizoctonia (Plate VII) often occurs on the pod, producing lesions which, particularly when they are small, closely resemble anthracnose. This fungus attacks only the pods lying in contact with the ground. The lesion has a bay to auburn center, often with a dark-colored ring near the margin surrounded by a ferruginous border. The lesions are more extensive than those of anthracnose, however, and do not contain the characteristic spore masses (Plate I).

Sclerotinia libertiana Fuckel produces a disease characterized by a soft brown rot and moldy appearance of the pod, followed by a shriveling and drying, which can never be confused with anthracnose. This fungus commonly produces rather large black sclerotia on the pods.

On pods of certain varieties, rust (Plate VIII) sometimes occurs as pustules containing a black mass of dusty spores.

When immature pods are exposed to the hot sun — as is often the case when the leaves are injured by blight or by other means, especially when the plants are approaching maturity — the exposed surfaces become discolored with brown specks, spots, or blotches, in some cases a little sunken, which may be mistaken for blight but hardly for anthracnose. MacMillan (1918) describes these lesions as he found them on certain varieties of beans in Colorado and in the East, and the writer has observed them commonly in the East on many varieties. A peculiar browning, different from sun-scald, was also observed, but the cause was not determined. A browning of pods may occur from other causes also, none of which, however, need be mistaken for anthracnose.

ETIOLOGIC ASPECTS

Name, classification, and synonymy of the causal organism

Bean anthracnose is known to be caused by the fungous parasite *Colletotrichum lindemuthianum* (Sacc. & Magn.) Bri. & Cav., one of the Melanconiales of the classification of Lindau (1900) as used in Engler and Prantl's *Die natürliche Pflanzenfamilien*. The fungus does not differ appreciably in its morphological characters from a number of other species belonging to this genus, nor, except for the presence of setae, from the genus Gloeosporium. Not only are species of the genus Colletotrichum

and of the related genus Gloeosporium similar in appearance, but also the diseases produced by species of the two genera are similar in character.

Saccardo (1878), in his description of the fungus, gave it the name *Gloeosporium lindemuthianum* Sacc. '& Magn. after Lindemuth, who discovered the fungus in 1875. Scribner (1888:364) described the presence of setae in the acervuli which were present on most specimens sent him from several States, and thought it probable that the generic name of the fungus should be changed to *Colletotrichum*. The following year Briosi and Cavara (1889) named the fungus *Colletotrichum lindemuthianum* (Sacc. & Magn.) Bri. & Cav., and distributed it as such. The same year Scribner (1889), again finding setae in the acervuli, placed the fungus in the genus Colletotrichum and published it as *Colletotrichum lindemuthianum* (Sacc. & Magn.) Scribner. The name given by Briosi and Cavara stands, although it is evident from much subsequent cultural work that the presence or absence of setae is not a character of sufficient stability to serve as a basis for the determination of generic position. Krüger (1913:294–303) was able to develop setose and non-setose cultures of this fungus at will, finding that a number of factors, such as age of the culture, and nature and moisture content of the substratum, were controlling agencies. He, however, designates the conidial form as *Gloeosporium* (subgenus *Colletotrichum*) *lindemuthianum* Sacc. & Magn.

Halsted (1893d), after making cross-inoculations on bean and watermelon, decided that the anthracnose fungi in these two hosts were the same, and used the name *Colletotrichum lagernarium* (Pass.) Ellis & Halsted, including in the synonymy the names that had been applied to the organism causing melon anthracnose and bean anthracnose, respectively. Shear and Wood (1913:46) found perithecia producing asci and ascospores in cultures made from an anthracnose spot on a bean pod, and they refer their fungus to *Glomerella lindemuthianum* Shear n. comb. Krüger (1913: 311), although he did not find perithecia, designates the fungus as *Glomerella lindemuthianum* Shear n. comb. Edgerton (1915:255–256) questions whether any perithecial stage of this fungus has ever been seen, and suggests that Shear and Wood might have been working with one of the saprophytic forms occurring commonly on bean pods. He believes the fungus should be considered as a species of Colletotrichum until further evidence supports a different view.

At various times other names have appeared in the synonymy of this fungus. Richon (1889) gives the name *Glaeosporium phaseoli* n. sp. to a fungus which he found on the pods and stems of beans at St. Amand, France. His meager description fits this fungus very well, and it is not improbable that he had before him the fungus causing bean anthracnose. Saccardo (1892) lists *Gloeosporium phaseoli* Rich. and gives Richon's description. Allescher (1903) also lists Richon's fungus and gives his description, but says that it is an uncertain species perhaps identical with *G. lindemuthianum* Sacc. & Magn. or with a Colletotrichum.

Allescher (1903) designates as *Gloeosporium lindemuthianum* Sacc. & Magn. forma *foliicolum* Allesch. the fungus he found on the upper surface of subcircular, brownish spots on leaves of *Phaseolus vulgaris* var. *nanus*. An examination made of type specimen No. 380 Allescher & Schnabl (1894), in the herbarium of the Pathological Collection of the United States Department of Agriculture, showed spots somewhat larger and more nearly circular than is usual for anthracnose but not sufficiently distinct to warrant the placing of the fungus as a form of the species. The spores are like those of *Colletotrichum lindemuthianum*. Allescher says the form *foliicolum* is similar to the type except in the appearance of the spots as described and in the absence of setae.

Desmazières (1843a) describes as *Septoria leguminum* Nob. a fungus on the pods of Phaseolus. He ascribes to variety "*b*" of the same species a form on Pisum. Saccardo (1878) says he is not able to decide whether or not *Septoria leguminum* Dsmz. should stand, as he cannot distinguish the young condition from *Gloeosporium lindemuthianum*, but the description varies widely from Septoria and approaches more nearly that of *G. fructigenum* Berk. Berkeley (1881), speaking of dried specimens distributed by Desmazières under the name *Septoria leguminum*, says the species shown is not a good representative of the genus Septoria, but belongs rather to Gloeosporium and has been figured by Saccardo in his *Fungi Italici* as *Gloeosporium lindemuthianum*. Cooke (1881), on the basis of Berkeley's observations, cites *Septoria leguminum* Desm. as synonymous with *Gloeosporium lindemuthianum* Sacc. Kirchner (1906: 137) ascribes to it the small, dry, sharply differentiated brown spots on beans, on which appear later very small black pimples.

Specimens of bean pods distributed by Desmazières (1843 b) as *Septoria leguminum*, deposited in the cryptogamic herbarium of the New

York Botanical Garden, show the presence of the fructifications of two fungi on one of the two pieces of pods in the packet. One of these, occurring in characteristic young anthracnose spots, has the typical spores of *Colletotrichum lindemuthianum* except that the average width, 5.75 μ, is a trifle greater. There can be no doubt that it is the bean anthracnose fungus. The other fungus appears on the specimen as numerous small black pycnidia and these contain typical Septoria spores. The other specimen shows only the Septoria-like fungus. Desmazière's description of the fungus given in *Annales des Sciences Naturelles* (1843 a), and also accompanying the specimen, is of the Septoria, but his description of the disease applies, at least in part, to the condition produced by the Colletotrichum. This probably led to the mistake of ascribing to *Septoria leguminum* Desm. the anthracnose present on pods of *Phaseolus vulgaris* distributed by Von Thümen (1882) as *S. leguminum* and by Roumeguère (1884) as *S. leguminum* Desm. var. *Phaseolarum.* Saccardo (1896) describes a fungus, which he names *Gloeosporium socium* Sacc., as occurring on the leaves of living bean plants (*Phaseolus vulgaris*). But from his description it seems improbable that he has the bean anthracnose fungus. D. Saccardo (1904) labeled as *Colletotrichum lindemuthianum* (Sacc. et Magn.) Cavara f. *brachysporum* specimens of a fungus on bean pod, *Phaseolus vulgaris*, the conidia and basidia of which were recorded as considerably shorter than the normal average. An examination of type specimens in the herbarium of the New York Botanical Garden shows small but typical anthracnose spots, from which, however, no spores were obtained.

Heald and Wolf (1911) have ascribed to a new species, *Colletotrichum caulicolum*, a destructive canker which they found on the stem of Kentucky Wonder beans in Texas. They say that this fungus differs from *C. lindemuthianum* in that the setae are produced abundantly in the host and that the spores are larger and are falcate. Their description of the disease and of the fungus is similar in most respects to that of bean anthracnose and its pathogene, but it is not possible from the description to decide that the fungi are the same. Cooke and Harkness (1880) report *Gloeosporium leguminis* C. & HK. on legumes in California, and later (1884) on pods of Robinia at Sacramento, California. Cooke (1880) describes *Discella leguminum* Cooke on the pods of Prosopis found in Texas. Comes (1891) lists *Discella leguminum* Cooke and *Gloeosporium leguminis* C. &

Hark. as synonyms of *Gloeosporium* (*Colletotrichum*) *Lindemuthianum* Sacc. & Magn. An examination of type specimens of these two fungi in the possession of Dr. C. L. Shear, of the United States Department of Agriculture, leads to the conclusion that they are not at all related to the fungus here considered.

The synonymy would, then, appear as follows:

Gloeosporium Lindemuthianum Sacc. & Magn. Michelia 1:129. 1878.
Septoria leguminum Desm. *In* Von Thümen, Mycotheca universalis, no. 2096. 1882.
Septoria Leguminum Desm. var. *Phaseolarum*. *In* Roumeguère, Fungi gallici exsiccati, no. 2791. 1884.
Colletotrichum lindemuthianum (Sacc. & Magn.) Bri. & Cav. I funghi parassiti delle piante coltivate od utili, no. 50. 1889.
Colletotrichum lindemuthianum (Sacc. & Magn.) Scribner. Orchard and garden 11:193–194. 1889.
? *Glaeosporium phaseoli* Ch. Rich. Cat. raison. champ. Départ. Marne, p. 401. 1889.
Colletotrichum lagernarium (Pass.) Ellis & Halsted. Bul. Torrey Bot. Club 20:246–250. 1893.
Gloeosporium Lindemuthianum Sacc. & Magn. forma *foliicolum* Allesch. *In* Allescher and Schnabl, Fungi bavarici exsiccati, no. 380. 1894.
Colletotrichum Lindemuthianum (Sacc. et Magn.) Cavara f. *brachysporum*. Mycotheca italici, no. 1364. 1904.
Glomerella lindemuthianum Shear n. comb. *In* Krüger, K. biol. Anst. Land- u. Forstw., Arb. 9:311. 1913.

Morphology and physiology

Spores

Whether the fungus is grown on its host or in culture media, the spores are produced abundantly on the surface in acervuli masses of a grenadine pink color. Frank (1883 b:513) mentions the presence of a slimy substance with the spores in the acervulus, and this has since been noted by other workers as a gelatinous substance in which the spores are embedded. If such a mass of spores is placed in water, they separate and become suspended in the water so that they are readily disseminated by its dispersal. If the acervulus remains dry, it hardens and shrinks down to small gray or brown granulations, and the spores are seldom set free under such circumstances.

The summer spores (conidia) are oval or oblong, cylindrical, one-celled bodies of somewhat variable size (Plate III, 1). They are straight or slightly curved, with the ends rounded or at one end somewhat pointed. The dimensions, as averaged from a large number of spore measurements, are 15 by 5 μ. The largest spore encountered measured 22 by 5.33 μ and the smallest 13 by 4.44 μ. The content of young spores is homo-

geneous and granular. Often there is a clear body resembling a vacuole near the center, which Edgerton (1910:20) describes as a nucleus but which earlier workers have regarded merely as a vacuole. Edgerton says that as the spore ages it becomes vacuolate, and finally the contents collect in small masses. The spores are no longer viable when this last stage is reached.

Spore germination

In making germination tests, spores from young acervuli produced in bean-pod cultures were transferred to a drop of the culture medium placed on a flamed slide. The slides were transferred to sterile moist chambers or petri dishes kept moist with wet blotting-paper, in which they rested on glass supports to hold them up from the bottom. The temperature was maintained at about 20° C.

Germination usually takes place by the protrusion of a germ tube from the side of the spore near one end and at an angle to its long axis. On nutrient media some spores have germinated within eight or nine hours (Plate III, 2). Bean agar gives the quickest and largest percentage of germination, although nutrient beef agar, potato agar, and beef bouillon give nearly similar results. Soon after the protrusion of the first tube, a second may be sent out from a similar point at the other end. As many as four germ tubes have been observed coming from a single spore, but rarely are there more than two. Dey (1919:307) observed in a few cases more than two germ tubes developing from a spore. The germ tubes form branches which radiate from it in all directions (Plate III, 4).

Germination takes place more slowly in water than in agar. A few spores were observed to have germinated in water after eighteen hours (Plate III, 10). In certain rain-water cultures about one-half of the spores germinated in twenty-four hours, but this was a greater proportion than the average. In distilled water, germination proceeded somewhat more slowly. The majority of the spores in these water cultures became uniseptate during germination, but septation was not observed to occur so commonly in spores germinating in nutrient solutions. Often there is a constriction of the spore at the septum. In some cases the spores themselves increased somewhat in size before or during germination, but this was not general and when spores were placed in nutrient solutions

it did not occur to any extent. Atkinson (1895) says that septation occurs unless the spore is very short, and that the spore becomes constricted at the point of septation soon after germination. He observed an increase in the size of the spores after germination until they became several times larger than at first, and states that even with spores which fail at first to germinate a similar increase in size takes place, and they become uniseptate, strongly constricted at the septum, and richly charged with highly refringent granules. Edgerton (1910:19) states that the spores swell but slightly or not at all in germinating in nutrient media if they are scattering, but if they are abundant and close together in the culture medium they swell to two or three times normal size in some cases. During the process of enlargement a septum is formed, and with further swelling a constriction of the spore appears at this point. Edgerton finds that "when there are more than 12 or 15 spores to the cubic millimeter of medium, the spores become swollen, germinate slowly and but poorly. When the number is less than this, they germinate with but little, if any, swelling" (page 20 of reference cited). He thinks this may be due to an enzyme prohibiting growth, given off by the spore during germination. Dey (1919) observed that if the drop of water used in the culture had a convex surface, the spores lying in the middle hardly germinated while most of those at the border did. He thinks this difference is due to a difference in the oxygen supply.

The germination of the spore in water consists, in most cases, of the production of an appressorium at one or both ends of the conidium (Plate III). This is a subglobose body flattened on one side, having dark-colored, thick walls and containing dense granular protoplasm. It often appears attached directly to the conidium or is produced at the end of a short germ tube, although it is not uncommon to find an appressorium at the end of a long, narrow hypha. In the ordinary process of germination in nutrient media, the spore contents become coarsely granular and the vacuole increases greatly in size or there may be several vacuoles. In rain-water cultures, the spore contents during germination seem to pass into the appressorium, in which the protoplasm appears to be very dense.

The appressoria in most cases are closely appressed to the slide. A few have been noticed, however, which were apparently free, as they were observed to move when the slide was jarred. In the course of twenty-four

hours some of these appressoria themselves send out a slender germ tube, at the end of which in most cases another appressorium is formed. After nine days about 50 per cent of the spores in this experiment had germinated but had not proceeded much beyond the production of appressoria. A number of spores had the appearance of being empty, and other peculiarities were noticed to which no importance could be attached.

Frank (1883 b: 513–515) describes the germination of the spore and the formation of appressoria, he being the first to apply the name to these bodies. These appressoria, Frank says, come to have a thick, irregular, dark purple membrane. They are produced abundantly when spores are germinated on the surface of bean or cucumber tissue, but seldom occur when germination takes place in water on a glass plate. Instead, long, thin, germ tubes are formed, at the end of which a small appressorium may appear, or the spore may produce another spore or sporidium attached directly to the spore or to a short tube. Frank says the appressoria do not germinate unless they are in contact with the host. He thinks their production is stimulated by the quality of the substratum, and suggests that their function is to prepare the fungus for penetration into its host plant.

Appressoria are produced by other Gloeosporia of the Glomerella type, and their significance has been discussed by other writers. Halsted (1893 a: 305) suggests that they may be formed as a protective body to tide the germinating spore over unfavorable periods. He says that, while the appressorium is often a single cell, it may become an aggregation of thick-walled cells like a sclerotium. He thinks the appressoria may be of taxonomic value. Stoneman (1898: 113) does not find them to occur as a constant character, but thinks they may be forced in certain species by lack of nourishment. Hasselbring (1906: 142), from studies of *Gloeosporium fructigenum* Berk., believes them to be adhesion organs during early stages of infection, and thinks they are formed as a result of contact stimuli of the germ tube but lose this power of reacting in nutrient media. He calls attention to the presence of a germ pore in the flattened side, through which the germ tube protrudes during germination. He finds the appressoria much more resistant to desiccation than the spores. Edgerton (1910: 21) finds appressoria produced in nutrient media, often not in contact with the glass or any solid substance; and in this species, *Colletotrichum lindemuthianum*, the "germ pore" is often lacking.

Gardner (1918:21), in his spore-germination studies of *Colletotrichum lagenarium*, concludes that a rather abundant supply of oxygen and a contact stimulus is necessary for appressorium formation, and that the presence of food material does not seem to inhibit such formation. Dey (1919), in his studies of *C. lindemuthianum*, states that appressoria are formed whenever the germ tube comes into contact with a hard foreign substance which acts as a stimulus for their formation. He found no germ pore in the appressoria observed, but noted that the germ tube arose from the side in contact with the glass. He observed the appressorium to be sheathed in a mucilaginous coat, which aids it in becoming attached to a foreign substance so firmly that even a jet of water fails to dislodge it.

In all the cultures made in fresh nutrient media, the germination was rapid, the germ tubes were as large, or nearly so, as the spores, few or no appressoria were formed, and the subsequent development of the mycelium was luxuriant; while in water cultures, the germination was slow, the germ tubes were much smaller in diameter, the production of appressoria was abundant, and subsequent development of mycelium was scanty or there was none at all. It is true that appressoria were commonly produced in nutrient media that was becoming somewhat dry and hard, as occurred soon when only a little was poured into a petri dish. When a nutrient medium is poured over a water culture, as suggested by Hasselbring (1906), the appressoria germinate within a few hours and produce a rich mycelial growth.

Mycelium and spore production in culture

Under favorable conditions for growth, the germ tube branches to form hyphae, and these in turn, by further growth and branching, develop within forty-eight hours into a mycelial mat often one millimeter in diameter. In three or four days conidia are produced at the ends of the hyphal threads. In several agar cultures in this experiment they were produced abundantly on short threads within twenty-four hours. They are formed by the constriction of the wall near the extremity of the hypha. A spore thus formed is pushed aside and the hypha elongates to about the same point, when constriction again occurs. In this way several spores are formed from a single branch, and can be seen lying side by side or piled in a heap at the end of the branch (Plate III, 5). Atkinson (1895:309) observed conidia being produced directly on the

spore, and in the writer's cultures this condition was frequently met. Atkinson found that the ends of the hyphal threads have a dichotomous appearance, due to a branch just behind the growing end overtaking the primary thread, and that a plumose tuft is produced by this dichotomous branching taking place successively in the same thread.

The mycelium, which at first is white, will become dark-colored after a growth of several days in a starch-containing medium. This is especially noticeable with the growth in potato agar and bean agar and on sterilized bean pods. A culture four or five days old shows a dark center with pure white mycelial growth at the margin and aërial mycelium developing over the surface. As growth continues, dark-colored knots of mycelial threads appear scattered from the center outward, and above these darker parts of the culture, flesh-colored masses of spores (acervuli) begin to be produced if the culture is in good condition. Dey (1919) finds that in cornmeal agar cultures these spores are surrounded by small dark spines. On sterilized bean pods inoculated with spores kept at a temperature of about 22° C., there is a rapid growth of mycelium which in two days begins to darken and after three days produces spores in acervuli. In six days the pod is covered with a pale salmon or pale flesh-colored mass of spores. Cultures kept for a long time or at unfavorably high temperatures lose their power to develop spores in this way when transferred to fresh media. Commonly they develop only a slow growth of white mycelium. Spores will usually be produced if the mycelium turns dark.

Viala and Pacottet (1905), from a study of *Colletotrichum lindemuthianum* in culture, report the production of spermagonia, pycnidia, cysts, yeasts, and sclerotia, as well as conidiophores, similar in most respects to those produced by *Manginia ampelina*, another fungus under their observation. Shear and Wood (1913:64) say yeasts have never occurred in their cultures of Gloeosporia except where they were evidently contaminations, and they have never observed the production of spermagonia or pycnidia by these fungi. No other writers in speaking of *C. lindemuthianum* or related forms have mentioned the production of bodies of these kinds, except that Edgerton (1910:10) reports having once found pycnidia-like bodies in the tissue of the bean seed.

Temperature is an important factor in the development of the fungus in connection with its host or in culture media. Edgerton (1910:29)

found that the fungus died in culture at Baton Rouge, Louisiana, during the summer, even when frequently transferred to fresh media, and later (1915) showed that the temperature requirements for this fungus are lower than for other anthracnose fungi, the optimum being about 22° to 23° C. though there is but little difference in growth between 19° and 26°. Edgerton gives the maximum as about 30° or 31° C. The growth at optimum temperatures is between 3 and 4 millimeters a day. Muncie (1917:9–11), after subjecting test-tube cultures of old mycelium to a water bath at 65° C. for ten minutes, found that good growth could yet be obtained but that the thermal death point of young mycelium lies between 50° and 52.5° C. and that of spores between 45° and 48° C.

The writer endeavored to determine the minimum, optimum, and maximum temperatures for growth and production of spores. Potato agar plate cultures of two physiologically different strains of *Colletotrichum lindemuthianum* were kept for a few days at 25° C., after which blocks of agar 3 millimeters in diameter of each strain were transferred to plates of potato agar and corn agar and to tubes of sterilized bean pods. The temperatures (centigrade) at which the cultures were placed were, respectively, 0°, 4°, 10°, 16°, 22°, 28°, 34°, 40°, 43°. Two cultures of each strain in potato agar and two of each in corn agar were placed at each of these temperatures on April 8, 1914. The growth made by them is shown graphically in figure 12.

It is seen that the average growth during the first six days was less than on the eight succeeding days at the temperatures 4° and 10° C., but was greater at temperatures above 28° C. Growth was probably checked during the first day or two at the lower temperatures by an abrupt transfer from a warm room, but was resumed to some extent later. While the growth was no doubt checked by the transfer to the higher temperatures, and ceased altogether after a few days at 34° and above, yet some growth was possible during the first day or two because the temperatures then ranged between room temperature, at which the cultures were started, and the higher temperatures. The figures giving the average growth on the eight days following the first six represent more nearly accurately the actual growth that occurs at these temperatures under these conditions. Considering, then, the curve representing such growth, it appears that the minimum temperature for growth lies at 0°, the optimum at 22°, and the maximum at 34°. As a matter of fact, the

minimum lies somewhere between 0° and 4° C., the optimum near 22°, and the maximum between 34° and a few degrees lower. This corresponds very closely to the observations of Edgerton (1915:254). The corn agar permitted a little better growth than the potato agar.

The growth at 4° C. was white, with considerable aërial mycelium in most cultures. After four weeks a growth of from 25 to 35 millimeters

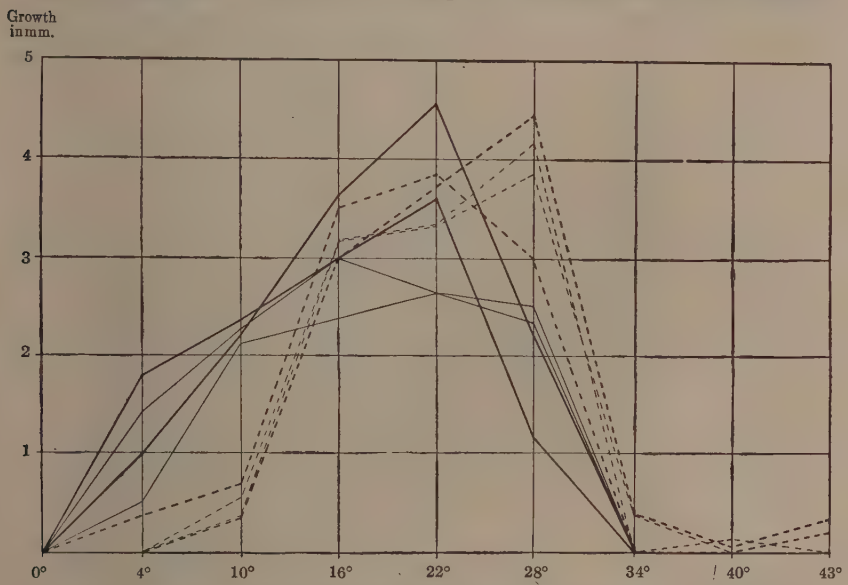

FIG. 12. CURVE OF GROWTH OF TWO STRAINS, A AND B, OF COLLETOTRICHUM LINDEMUTHIANUM AT VARYING TEMPERATURES

The light curves represent growth in potato agar, the heavy curves growth in corn agar. The dotted lines represent average growth per day during the first six days; the straight lines, average growth per day during the following eight days. The temperature is expressed in degrees centigrade

was attained, and an olivaceous color, with spore production, was noticed in a few agar and bean-pod cultures. Spores were produced in abundance on bean pods at 10°, 16°, and 22° in six days, and but sparingly at 28°. As already stated (page 121), bean pod cultures kept at 22° C. have been found to give a rapid and abundant production of spores when the fungus was in a spore-producing condition, in hundreds of cultures made by the writer.

The relation of growth of this fungus to acid and alkaline media has not been studied by the writer, though he has observed that not as good growth is secured when the fungus is cultured in a potato-agar medium made acid by the addition of one drop of 50-per-cent lactic acid to 10 cubic centimeters of medium, as when such acid is not added. Edgerton (1910:28) records a fair growth of *Colletotrichum lindemuthianum* at −16 Fuller's scale, excellent growth at +5, and only slight growth at +20. *Glomerella gossypii* (South.) Edg. grew better than did *Colletotrichum lindemuthianum* in the more acid media.

The ascogenous stage

The ascogenous stage of many anthracnoses has already been found in nature or produced in culture. Klebahn (1905) has shown that the Gloeosporium causing sycamore anthracnose is a Gnomonia. He also (1907:65) found the perfect stage of *Gloeosporium ribes* (Lib.) M. & D., causing an anthracnose of currant leaves, to be a Pseudopeziza. Burkholder (1917:164) discovered the perfect stage of *Gloeosporium venetum* Speg. on raspberries to be a Plectodiscella, which he named *P. veneta* Burkholder. Genera representing perfect stages of other Gloeosporia that have been reported (Stevens, 1913) are Glomerella, Gnomoniella, Gnomonia, Trochila, Physalospora, and Calospora. Most of the anthracnose fungi parasitic on fruits and herbaceous plants, including the one on bean, belong to what is known as the Glomerella type, that is, their perfect stage when found is of the type of the genus Glomerella. Even in their imperfect stage they differ somewhat from the other forms. Edgerton (1908:384) has pointed out the following important differences, among others of minor importance:

Glomerella type	Gnomonia and Pseudopeziza types
Spores oozing out as a pink mass	Spore mass white, cream-colored, or yellow
Appressoria produced in certain cultures under certain conditions	No appressoria observed
Mycelium in culture varying but little in diameter	Mycelium in culture varying in diameter (at least in Gnomonia type)

Stoneman (1898:99–112) was the first to discover the ascogenous stage of a Gloeosporium of the Glomerella type, and she described five species occurring in nature or in culture. These were placed in a new genus of the Gnomoniaceae which Stoneman named Gnomoniopsis. Since then the perfect stages of at least thirty-two other Gloeosporia or Colletotricha have been found in nature or produced in culture. Von Schrenk and Spaulding (1903), because of a prior use of the name Gnomoniopsis, substituted for it the name Glomerella.

Shear and Wood (1907, a and b, and 1909) have produced in culture the perfect stage of anthracnose fungi from a large number of hosts, and among them what they believed to be the ascigerous perithecia of *Colletotrichum lindemuthianum*. They say that light, temperature, and moisture are not factors of much importance in producing this stage. They hold that once a race, a strain, or a generation is obtained that will produce the perithecia, these may be produced in various media and under diverse conditions. Moreover, they state that if a given strain will not produce perithecia in sterilized cornmeal at 75° to 85° F., it is useless to try longer to obtain them from that strain. In a later publication (1913:14), after having studied forms on forty-five different hosts and having obtained the ascogenous stage from thirty-six hosts, they refer forms from thirty-nine hosts to *Glomerella cingulata* (Stonem.) S. et v. S., the one from cotton to *Glomerella gossypii* Edg., the one from bean to *Glomerella lindemuthianum Shear*, those from watermelon, cucumber, and squash to *Gloeosporium lagenarium* (Pass.) Sacc. & Roum., and the one from banana to *Gloeosporium musarum* Cke. & Mass.

In the same publication (1913:46–47) Shear and Wood record the finding of perithecia producing asci and ascospores in flasks of cornmeal from cultures made from an anthracnose spot on a bean pod. While the perithecia were abundant, conidia were scarce or wanting. Numerous subsequent plate cultures made from crushed perithecia and asci and from single ascospores produced the usual growth of mycelium and abundance of perithecia with mature asci, but no conidia were seen. Shear and Wood believe this form to be an extreme variation of a condition they have noticed in respect to cultures from other hosts, in that cultures from ascospores produce fewer conidia than do cultures made from conidia.

Edgerton (1915:255) thinks it doubtful that any perithecial stage of *Colletotrichum lindemuthianum* has ever been seen, and that Shear

and Wood were not working with a culture of the true bean-anthracnose fungus but rather with one of the saprophytic forms which Edgerton finds occurring commonly on old parts of bean and other plants. These forms produce perithecia abundantly, but no conidia. In hundreds of cultures of *C. lindemuthianum* examined by him, no perithecia have been found, and he thinks that until more satisfactory proof is offered of the presence of perithecia it is better to consider the bean anthracnose fungus as lacking an ascogenous stage.

Relation of fungus to host

Penetration of the host

Frank (1883b:515) described in detail the germination of the spore and the penetration of the host. He says that the spore, on germinating, produces a germ tube, which on coming into contact with the epidermis of the host forms an appressorium closely pressed against the surface of the epidermis. This either remains unchanged, or after a time becomes thinner and colorless on one side, and from this spot a germ tube appears. The germ tube penetrates directly through the cuticle into the epidermal cell, and either fills this cell with branching hyphae or quickly penetrates the adjoining epidermal cells or those beneath. Voglino (1892), from inoculations of parts of green bean pods, observed the germination of the spore, the quick formation of large numbers of appressoria, and the production of mycelial filament which penetrated into the interior of the epidermal cells. Dey (1919) has carefully studied and figured this penetration from stained sections made from material embedded in paraffin. He finds that a peg-like infection hypha grows out from the surface of the appressorium in contact with the host, which mechanically ruptures the cuticular layer and then brings about a swelling and disintegration of the subcuticular layers — probably by enzymic action. The infection hypha was never observed earlier than forty-eight hours after inoculation. The rupture of the cuticle is the result of the pressure exerted by the development of the infection hypha. This hypha is very fine at first, but reaches a normal size while growing in the cellulose layers below the cuticle. Here, or farther on in the cell, it produces a small vesicle from which one or more branches arise and extend into the host tissue. As the invading hypha enters the cell, the protoplasmic contents collect around it, and later a collapse of the cell takes place. The writer has never observed this

penetration. It seems that this is the really critical time in the development of the fungus, for it must overcome the protoplasm of the host cell before it can continue its development. Varieties of beans immune to certain strains of *Colletotrichum lindemuthianum* probably owe this immunity to the inability of the infection hypha of the fungus to overcome the resistance offered it by the protoplasm of the host cell. The writer (Barrus, 1918:594) has shown that some such varieties, on inoculation with such a strain, have shown on their pods and stems a slight but distinct specking, as though the fungus had entered the tissue and killed a few cells but was unable to proceed farther. This specking did not appear on the pods of plants not inoculated.

Once the fungus has established itself within the host cell, the hyphae extend horizontally and diagonally into other cells, penetrating the cell walls of the host as they come into contact with them. (Plate II). In some cases the hyphae enlarge when in contact with the cell wall, and a small hole is formed through which projects a slender tube that at once enlarges after passing through. As many as twelve hyphae have been observed penetrating a single cell (Plate II, 4). Growth within the host is rapid, particularly if the tissue is young and tender. The protoplasm of the host cell is killed and turns brown soon after being attacked. The walls collapse, and after from four and one-half to seven days a lesion may be observed on the surface.

There seems to be a great difference of opinion as to the length of the period of incubation. Frank (1883a:33) noticed the beginning of a browning of the epidermis at separate points on the pods twenty-four hours after inoculation was made. This browning had extended by the following day, and five days after inoculation Frank obtained the first spores in the new lesion. Scribner (1888) states that the cells become discolored almost at once after the hyphae enter. Halsted (1892:284) found a spot on an otherwise healthy pod thirty-six hours after inoculating it in the laboratory under the most favorable conditions. Pammel and King (1909) report having obtained an anthracnose spot thirty-six hours after inoculation. Dey (1919) claims that early specking appears on a pod when tap water is substituted for infection drops, and thinks it due to osmotic disturbances. Edgerton (1910:14) finds from inoculations made on plants in the greenhouse and in the field that the period of incubation ranges from four and one-half to nine days, depending on the

weather and on temperature conditions. The writer's numerous observations are in accord with this as regards the production of typical anthracnose lesions. Temperature appears to have some influence on the length of the incubation period; also, the period varies considerably with the different varieties of beans under the same conditions. Schaffnit (1920) finds that the incubation period, and also the period between infection and spore formation, differ with different varieties.

Reproduction of the fungus within the host

At about the time when the cell walls collapse to form a canker, or even earlier in many cases, the mycelium at certain points develops abundantly in the epidermal cells and in those just beneath, forming a stroma of closely crowded, many-septate hyphae. The host cells at these places are so flattened that it is difficult to observe them (Plate II, 2). From this pseudoparenchymatous tissue arise short, more or less erect, conidiophores, from 15 to 20 μ long and from 4 to 5 μ broad, at the apex of each of which is borne a small conidium rounded at the top and drawn out to a point at its attached end. This conidium enlarges somewhat before becoming detached. The conidia are formed by the constriction of the upper end of the conidiophores, as described in connection with germination in culture media. Spore after spore is produced by the conidiophore; the cuticle, which has been pushed up to form black pimples in the canker as the conidiophores elongate, is soon ruptured, and the spores emerge in a gelatinous pink mass (Plate I, 1) Frank (1883b: 513) describes the formation of the stroma and the production of spores enveloped in slime, the rupture of the cuticle, and the behavior of the spores thereafter.

These first acervuli formed at the center are followed by the production of others as the lesion enlarges. In a single lesion there may be fifty or more acervuli, in which thousands of spores are produced. Edgerton (1910: 12) estimated that on a badly spotted pod, from 110,000,000 to 115,000,000 spores had been produced. After washing these off and placing the pods in a moist chamber for twenty-four hours, he found that about 50,000,000 more spores were produced, and he concluded that a total of from 500,000,000 to 1,000,000,000 spores may develop on some pods. If the weather remains moist and cool, the conidiophores will continue to produce conidia; but during dry weather the spore masses harden down over the acervulus and spore formation ceases.

As the acervuli become older, long-pointed, brown, septate hyphae (setae) are produced here and there among the conidiophores and often in a ring near the margin. These range in length from 30 to 90 μ. Some taper evenly to a point from a base 8 to 10 μ wide; others have a bulbous base, which Beach (1892:319) reports as being often many-celled; many do not taper evenly but are swollen near the septa. They vary in number from a few to as many as twenty in an acervulus (Plate I, 2). Black stromata made up of dark-colored hyphae are produced on the surface of dead areas of leaves spotted by anthracnose and on the surface of dry pods, and these invariably support setae. Setae are abundantly formed also in old agar and bean-pod cultures. Frank (1883 b:517) found them in lesions on bean pods, and describes them as sterile, brown, hair-like appendages of the fungus.

The fungus in the seed

The fungus passes the winter in the seed as mycelium lying within the cells in a more or less dormant condition. It may be confined to the cells of the seed coat, but in badly diseased seeds it occurs in the cells of the cotyledon. It exists there as vacuolate, closely septate, hyphae, from 3 to 5 μ in diameter, which are wound about in the cells or extend diagonally across into other cells. It may occasionally be found as a cobwebby growth between the seed coat and the cotyledon, or even between the two cotyledons within the seed. Frank (1883 b:520) found spores produced in lesions of the seed, Scribner (1888) says that spores and basidia may be found between testa and embryo, and Halsted (1892:285) found them borne in the cavity between the cotyledons of the diseased dry seed. Halsted called attention to the rapid growth of the fungus and to the production of spores on the diseased seed when it is placed under a bell jar. Edgerton (1910:10) notes that acervuli are often present on the surface of the spots and between the cotyledons, and finds peculiar closed pycnidia-like bodies buried some distance beneath the surface of the bean.

Gain (1898) has shown that the density of attacked seeds may be lowered as much as 4.7 per cent. Muncie (1917:37) states that badly affected seed will remain on the surface of a solution of sodium nitrate of given concentration, while slightly affected and clean seed will sink in it.

The viability of the seed also is affected according as the mycelium has or has not penetrated beyond the epidermis which protects the embryo. Gain (1898 and 1899) says that 10 per cent of the affected seed planted did not germinate, 8 per cent germinated but did not grow, and 36 per cent, although affected, were viable; while 46 per cent having only the integument but not the cotyledon affected produced healthy plants, as the fungus cannot produce fructifications unless it has penetrated into the cotyledon. Seed affected to one-twentieth of their volume are not viable. Gain says also that the disease can be quickly communicated from one seed to another by contact, or by inoculation with spores. Halsted (1892) states that only half of the diseased seed germinated, and those that did germinate produced plants of a sickly nature. Observations made by various other workers seem to prove that affected seed germinates poorly. The experience of the writer indicates that the percentage of germination of anthracnose-affected seeds is dependent mainly on the tissue affected and the area of the lesion. If the embryo or the tissues near it are affected, the seed usually will not germinate. When conditions are far from optimum for germination of bean seed, affected seeds often do not germinate, but neither will healthy seed germinate well under such conditions. The larger proportion of plants appearing from healthy seed than from affected seed under unfavorable conditions for germination is due to the attack of the new tissues by the anthracnose fungus and sometimes by other fungi associated with it. Edgerton (1910:36) obtained a much lower percentage of germination from anthracnose-spotted seed planted in unsterilized soil than from that planted in soil that had been sterilized, due to rot organisms in the unsterilized soil which attacked such seed. He says, however, that in the latter case the great majority of plants appearing were destroyed by anthracnose, while in the former there was greater freedom from the disease, indicating to him, as did other trials and observations, that rot organisms of the soil, especially a certain Fusarium commonly associated with anthracnose spots on seed after planting, will in Louisiana greatly reduce the severity of the anthracnose.

It appears that when a diseased seed is placed in a fairly moist situation, the threads of the fungus, theretofore dormant, renew their activity, extending into healthy cells beyond and forming spore-bearing conidiophores at the surface of the lesion. These conidiophores appear first as small black pimples in the lesion, from which spores issue in small,

pinkish, pasty masses. As already mentioned, if the acervulus remains dry these spores harden down to little gray or brown granulations, and the spores are seldom set free under such circumstances. Ordinarily the lesion becomes wet with soil moisture or later with rain or dew, and then the spores separate from one another and become suspended in the water. Sometimes the entire seed becomes enveloped by a moldy growth of the fungus and fails to germinate; but when a diseased seed is viable and soil conditions are favorable, spores may be produced in the diseased parts of the cotyledons by the time they have appeared above ground. If the soil is sufficiently moist as the seed is emerging from the ground, spores are set free and these are able to infect the young and tender stems.

Infection of the seedling from affected seed

The plumule, consisting of the young leaves, is during germination and for a short time thereafter in intimate contact with the cotyledons (fig. 13). The water containing the suspended spores, by capillarity and

FIG. 13. SEEDLINGS PHOTOGRAPHED TO ILLUSTRATE MANNER OF INOCULATION OF JUVENILE LEAVES FROM SPORES PRODUCED ON COTYLEDON
Seven-eighths natural size

in other ways comes into contact with the now exposed under surface of these leaves. The stem may also become inoculated with spores that have been washed down from the cankers on the cotyledons, especially the base of the stem just below the surface of the soil, where moisture conditions are favorable for the germination of the spores. Frank (1883b:522) says that after affected cotyledons fall from the growing seedling, the fungus continues to grow in them and produces spores in great abundance which are washed by rain into the soil and bring about an infection of the plant in this way. Spattering of contaminated water and of soil also serves to inoculate the seedling; this is discussed more fully later.

Dipping seed in a suspension of spores just before planting will bring about an infection of the cotyledons and other parts of the seedlings, as has been shown by Edgerton (1910:41) and verified by the writer. Gain (1898) proved that the soil can become contaminated and serve as a source of inoculum.

Seeds planted in soil to which water containing spores of this fungus is applied will also produce infection. On August 22, 1910, thirty-six clean bean seeds were planted in twelve pots and watered with a suspension of spores of *Colletotrichum lindemuthianum*. As a check, six seeds were planted in two pots to which water without spores was applied. On September 6 thirty-one plants had appeared in the twelve pots, of which thirty, or 96.8 per cent, were infected. None of the six plants that appeared in the check pots were affected. On August 30, 1910, fifty clean seeds of the variety Golden Refugee were planted in a flat in clean soil, and water containing spores of *C. lindemuthianum* was poured over the surface until the soil was wet. On September 9 forty-nine plants had appeared, of which six showed anthracnose lesions. No later observations were made.

Longevity of fungus in soil

In order to find out whether spores washed to the soil would remain viable over winter, the following experiment was carried out. On November 27, 1916, twenty-five 8-inch pots were filled with loam and sterilized in the autoclave for three hours at twenty pounds pressure. On December 15, fifty test-tube cultures of *C. lindemuthianum* grown on

sterilized bean pods were placed in 4 liters of tap water and the spores were washed off. The suspension was then filtered through a mat of absorbent cotton to eliminate fragments of plant tissue. Twenty-one pots of soil were inoculated by pouring over the surface of each about an equal portion of the suspension. There being some of the suspension left over from the first application, a double portion was applied to three pots. Four pots did not receive any spores, and these were labeled *Checks*. Several thicknesses of cheesecloth were tied over the top of each pot and the pots were placed outdoors. In the course of the winter and spring, the pots were taken into the greenhouse and planted with Davis White Wax, a susceptible variety, the seed used having come from healthy pods and having been carefully sorted. Twenty-five seeds were planted in each pot. After the beans were planted, unused sphagnum was placed over the surface to the depth of an inch to keep the surface of the soil in a moist condition. At the last trial, on June 8, four of the pots were inoculated again with a fresh suspension of spores as a control. The results are given in table 3. It was thought that the pots planted on

TABLE 3. RESULTS OBTAINED BY GROWING BEANS IN SOIL THAT HAD BEEN INOCULATED WITH A SUSPENSION OF SPORES OF COLLETOTRICHUM LINDEMUTHIANUM, AS COMPARED WITH THOSE GROWN IN UNINOCULATED SOIL

Date of planting	Date of examination	Type of inoculation	Number of plants appearing	Number of plants affected	Remarks
Dec. 15, 1916	Jan. 6, 1917	2 single	25	11	Small lesion at base of stem
			25	2	Ditto
Jan. 30, 1917	Feb. 25	1 double	21	17	Well-defined lesions on stem
		1 single	24	2	Ditto
		1 check	23	0	
April 13	May 7	2 double	25	0	
			24	0	
		3 single	24	0	
			25	0	
			25	0	
		1 check	24	0	
Pots replanted May 7	May 29	2 double	25	4	Well-defined lesions on stem. All 4 affected plants adjoining
			24	0	
			22	0	
		3 single	22	1	1 small lesion on stem
			24	0	
		1 check	24	0	

TABLE 3 (*continued*)

Date of planting	Date of examination	Type of inoculation	Number of plants appearing	Number of plants affected	Remarks
June 8	June 24	8 single	23	0	
			24	1	5 old lesions on stem
			25	0	
			23	0	
			22	3	1 with several old lesions. 2 with new lesions, apparently secondary infection
			25	2	2 with one new lesion, apparently secondary infection
			25	0	
			25	1	4 old lesions
		2 checks, not inoculated	25	0	
			25	0	
		4 recently inoculated	24	24	Stems badly affected
			22	22	Ditto
			22	19	Ditto
			24	17	Ditto

April 13 may not have given infected plants because the surface of the soil had been allowed to remain dry for some time through neglect. As no new spores had been produced to vitiate the experiment, these pots were replanted on May 7.

It would appear from this experiment that a few spores are able to live over winter in the soil outdoors and bring about infection the following spring. It is but fair to say, however, that the plants were not in any case screened from greenhouse insects that were present, and that other inoculation experiments with bean anthracnose were being conducted by other persons in another compartment of the same house and in adjoining houses. This may account for the few cases of disease occurring in the spring experiments. The infection is very light compared with that occurring on plants grown in freshly inoculated soil. Under practical bean-growing conditions the chances of infection from this source must be negligible.

An experiment similar to the one recorded above was tried the following winter, the same methods being employed. A greater effort was made, however, to keep the surface of the soil moist at all times, and also unsterilized but presumably uncontaminated soil, as well as sterilized soil, was used. On January 5, 1918, all the pots were well moistened with tap water, soon after which a suspension of spores was poured over the

surface of the soil of those to be inoculated. Sterilized sphagnum was then placed over the soil to the depth of an inch, and covers were tied over the tops of the pots. After three days some of the pots were placed outdoors, being set in the soil so that the tops were level with the surface of the ground; others were left inside the violet house, where the temperature is kept cool. Check pots not inoculated were similarly prepared. At each planting made thereafter a control pot, made up of fresh uncontaminated soil, was inoculated in the same manner as were the pots inoculated earlier. Twenty-five clean beans of the variety Refugee Wax were planted in each pot except in the first planting, when the variety Extra Early Refugee was used. After planting, the pots were kept in the warm house. The results are given in table 4.

TABLE 4. RESULTS OBTAINED BY PLANTING BEANS AT VARIOUS TIMES IN SOIL INOCULATED WITH A SUSPENSION OF SPORES OF COLLETOTRICHUM LINDEMUTHIANUM, AS COMPARED WITH THOSE GROWN IN UNINOCULATED SOIL

Date of planting	Date of examination	Description of pots used	Number of plants appearing	Number of plants affected	Remarks
Jan. 5, 1918	Jan. 25, 1918	Check (not inoculated):			
		Soil sterilized	25	0	
		Inoculated:			
		Soil not sterilized	22	21	Varying from 2 excellent, to those with a slight lesion at base of stem
Jan. 17	Feb. 17	Check (not inoculated):			
		Pots left outside:			
		Soil sterilized	17	0	
		Inoculated:			
		Pots left outside:			
		Soil sterilized	21	1	Slight lesion on stem
		Soil not sterilized	7	0	
		Pots left inside:			
		Soil sterilized	23	2	Fair halfway up stem
		Soil not sterilized	17	5	One or more lesions on stem
Feb. 20	March 11	Check (not inoculated):			
		Pots left outside:			
		Soil sterilized	21	0	
		Soil not sterilized	13	0	
		Inoculated:			
		Pots left outside:			
		Soil sterilized	20	0	
		Soil not sterilized	15	0	
		Pots left inside:			
		Soil sterilized	20	0	
		Control (fresh soil used):			
		Soil inoculated 2–20–18	19	19	Lesions, many of them large, on stems

TABLE 4 (*continued*)

Date of planting	Date of examination	Description of pots used	Number of plants appearing	Number of plants affected	Remarks
April 3	April 19	Checks (not inoculated):			
		Pots left outside:			
		Soil sterilized.....	24	0	
		Soil sterilized.....	18	0	
		Inoculated:			
		Pots left outside:			
		Soil sterilized.....	22	0	
		Soil sterilized.....	19	0	
		Soil sterilized.....	19	0	
		Soil not sterilized....	25	0	
		Soil not sterilized....	18	0	
		Pots left inside:			
		Soil sterilized.....	24	0	
		Soil sterilized.....	19	0	
		Soil not sterilized....	13	0	
		Control (fresh soil used):			
		Soil inoculated 4–3–18..	16	13	Excellent on stems

It appears fairly evident that spores of *C. lindemuthianum* removed from the acervulus and remaining in the soil for a period of two weeks or more are able to bring about an infection of susceptible bean seedlings grown in such soil, but not after six and one-half weeks. Under field conditions, however, in addition to spores being washed into the soil, there are many bits of plant tissue, some of which would probably be infected tissue, remaining on the soil after the beans are harvested.

Frank (1883 b:521) tested the germination of spores which he found produced in the lesions of dry seed. He concludes that spores attached to the basidium remain viable throughout the winter, while those produced earlier and unattached are unable to survive. Edgerton (1910:25) has studied in a different way the question of the viability of these spores. He finds that the old spores on or within affected seeds are capable of germinating in nutrient media, and suggests the possibility of the infection of seedlings from healthy seeds by such spores, they having been transferred to the healthy seed by contact with affected ones. He finds also that good germination takes place in agar after the spores have remained dried for thirteen days in their mucilaginous matrix or washed free from it, and states that some germination took place after twenty-two days had elapsed.

Infection was also brought about, in an experiment, by placing recently affected vines or pods on or in the soil before the bean plants appeared. On August 8, 1910, vines of the current year badly affected with anthracnose were placed in a flat and covered to the depth of an inch with soil. On the surface of this soil, fifty hand-sorted Refugee Wax bean seeds were planted. These were covered lightly with soil. The soil came from a neighboring field that had not produced beans for years. The flat was then placed outdoors and watered once with well water. All the seeds produced plants, which on August 22 were not affected on any part above ground. On August 29 forty-two plants had appeared, of which thirty-five, or $83\frac{1}{3}$ per cent, showed lesions on stem, on leaves, or on both.

On August 22 one hundred clean Refugee Wax seeds were planted in clean soil in a flat and covered lightly with soil. Over the surface was placed a quantity of immature pods badly spotted with anthracnose and producing spores. On September 6 ninety-eight plants had appeared, of which ninety-four, or 95.9 per cent, were infected.

Halsted (1896:286) has shown how beans planted in ground on which diseased plants were grown the year before, gave from four to six times as many spotted pods as did beans grown on new land; he found also (1896:288 and 1897:330) that mulching the soil with diseased pods from the preceding season caused an increase in the number of spotted pods over those in soil mulched with hay. This would lead to the belief that the fungus is capable of living over winter as spores in the soil or as spores or mycelium in the diseased pods.

Observations were made each year from 1910 to 1914 to determine whether soil which the preceding year had produced plants badly affected with anthracnose could serve as a source of inoculum to seedlings. Healthy seed planted in such soil gave in every instance seedlings that were free from anthracnose and remained so for a considerable time afterward.

Tests were made to determine whether the fungus can live over winter in old pods and vines. Badly spotted pods stored in paper sacks in an attic were found during the late winter and early spring to possess a thin black mycelial growth over their surface outside of the old lesions, and scattered thickly in places on this growth were small black bodies

resembling pycnidia as viewed with a hand lens (fig. 14). A section through these bodies examined under the microscope showed them to be compact

FIG. 14. SAPROPHYTIC DEVELOPMENT OF ANTHRACNOSE ON SURFACE OF DRY PODS

acervuli containing a large number of setae. The conidia, present in large numbers, germinated readily in a nutrient solution, and when healthy plants were inoculated with them anthracnose lesions appeared. The

growth seems to be of a saprophytic nature, as the pods were dry when picked and at that time none of this growth was observed. Other isolations of *C. lindemuthianum* have been made from dry bean pods from time to time, even from pods more than a year old.

Trials were made also to determine whether old pods and vines affected by anthracnose may serve as a source of inoculum to seedlings. In the fall of 1911 a plot of ground where anthracnose had appeared to a severe extent on beans was selected for experiment. The diseased vines were left there, and diseased vines from other places were spread on the plot, all being plowed under the following spring. On June 13 a short row of each of five varieties was planted with seed from selected healthy pods. Adjoining these, one row of each of two varieties was planted with seed spotted with anthracnose. The seedlings were appearing on June 19. In several examinations made before June 25, the plants from the healthy seed showed no affection with anthracnose, while the young leaves of the plants from spotted seed were severely affected. Eight plants from healthy seed were found to be affected on July 1 as shown in table 5. This may have been due to secondary infection. The order in which the varieties appear in the table is the order in which they were planted in the plot.

TABLE 5. RESULTS OF AN EXPERIMENT TO DETERMINE WHETHER OLD PODS AND VINES AFFECTED WITH ANTHRACNOSE CAN SERVE AS A SOURCE OF INOCULUM TO SEEDLINGS

(Seed planted on June 13, 1912; data taken on July 1, 1912)

	Varieties planted with healthy seed					Varieties planted with seed spotted with anthracnose	
	Blue Pod Medium	Turtle Soup	California Cream	Navy Pea	Red Marrow	Navy Pea	Red Marrow
Number of plants appearing.	306	492	346	1,070	1,473	198	262
Number affected with anthracnose.....	0	0	1	2	5	81	95
Per cent affected with anthracnose.....	0	0	0.3	0.2	0.3	41	36

While observations were made each year as to the possibility of infection of seedlings from overwintered vines, no further definite efforts were made to determine this point until the fall of 1915, when a series of experiments

was planned with this end in view. In these experiments the beans were planted in soil in ordinary greenhouse flats. Each flat was numbered, and the conditions involved in the case of each are given herewith. Seeds from healthy pods were used for planting each flat except flat 2, for which seeds spotted with anthracnose were used.

Flat	Description
1	Clean soil
2	Clean soil. Seeds spotted with anthracnose used in planting
3	Contaminated soil
4	Contaminated soil sifted to remove particles of bean tissue
5	Clean soil. Diseased vines and pods from crop of 1915 obtained from disease garden, broken up and mixed with soil in flat
6	Clean soil. Diseased vines and pods from crop of 1915 obtained from disease garden, placed on surface of soil and removed as seedlings were appearing
7	Clean soil. Diseased vines and pods from crop of 1915 obtained from disease garden, placed on surface of soil and left there
8	Clean soil. Diseased vines and pods from crop of 1915 kept in seed house, placed on surface of soil and left there
9	Clean soil. Diseased pods from crop of 1916 kept in seed house, placed on surface of soil and left there

The clean soil (uncontaminated by *C. lindemuthianum*) used was taken from a field where no beans had ever been grown so far as was known, but it was not sterilized except in the last experiment, when it was thought to be contaminated with spores. The flats, unless new, were sterilized with steam. The contaminated soil came from places in the disease garden where bean plants badly affected with anthracnose had grown in 1915. Only the surface soil to a depth of from two to four inches was used. In the first experiment both sifted and unsifted soil was used, but thereafter all contaminated soil was passed through a rather fine sieve in order to remove particles of bean-plant tissue as far as possible.

The healthy seed used was selected from clean pods, and in all but two experiments (II and III) it was immersed for three minutes in a 1-1000 mercuric chloride solution and afterward washed in tap water. This was done to destroy any spores of *C. lindemuthianum* that might possibly be present. The affected seed was disinfected in the same way as was the healthy seed. Seed so badly diseased that it could not germinate was not used. The affected seed used in each experiment was of the same

variety as the healthy seed used. Davis White Wax was used in all experiments except Experiment IV, in which Refugee Wax was used. The old vines and pods affected by anthracnose were of several varieties and no attempt was made to keep them separate. Most of them were well covered with anthracnose lesions. Care was taken to remove all seeds, even shriveled ones, from the pods. The vines and the pods left in the garden over winter were much overrun with numerous saprophytic fungi and were somewhat decomposed by spring. Those kept in the seed house were as intact as they were when placed there.

In setting up an experiment, for example flat 6, the soil was first placed in the flat, the seed was then disinfected and planted usually in four or five rows to a flat, the vines and pods were placed over the surface to a depth of about one and one-half or two inches, the flat was placed in the greenhouse, and tap water was sprinkled on it until the soil was saturated. Unused sphagnum was placed over the flats unmulched by pods or vines in the case of Experiments V and VI. Each flat was prepared separately and every precaution was taken to avoid contaminating one with another.

The temperatures at which the flats were kept in the different experiments varied considerably, but when possible they were kept between 65° and 70° F. This was done in order to favor the fungus and permit infection to take place, and for this reason also the flats were watered more profusely than is best for good germination of bean seed. As a result the germination was very poor in some instances.

Records giving the extent of affection are not included here as they are all very much alike. On nearly every plant the stem was affected with one or more lesions, and often these occurred only at the surface of the ground. A few plants had lesions on the leaves. Lesions on cotyledons coming from the spotted seed used in flat 2 were not considered. The records were usually taken in about three weeks or less after the experiment was set up, in order to get them before secondary infection occurred. There is no doubt that secondary infection did occasionally occur.

These experiments, the results of which are shown in table 6, cannot be regarded as ideal. The results obtained in some cases — for example, from flat 1 in Experiment II — may seem to cast doubt on their reliability. But when the entire series is considered, there can be no doubt that the results show the possibility that old bean pods and vines serve as a source

TABLE 6. RESULTS OF A SERIES OF EXPERIMEN S TO DETERMINE WHETHER CONTAMINATED SOIL OR ANTHRACNOSE-AFFECTED VINES AND PODS OF VARIOUS AGES CAN SERVE AS A SOURCE OF INOCULUM TO BEAN SEEDLINGS

Experiment, and date when set	Flat	Number of plants appearing	Plants affected	
			Number	Per cent
I Nov. 24, 1915	1	12	0	0
	2	47	12	26
	3	24	0	0
	4	35	16	46
	5	24	19	79
	6	17	15	88
	7	14	14	100
II Dec. 29, 1915	1	44	11	25
	2	26	16	62
	4	45	0	0
	5	47	31	66
	6	24	21	88
	7	48	28	58
III April 28, 1916	1	35	0	0
	2	33	16	48
	4	41	0	0
	5	32	2	6
	6	25	5	20
	7	30	4	13
	8	18	15	83
IV June 7, 1916	1	38	0	0
	2	22	21	95
	4	37	0	0
	5	40	2	5
	6	39	1	3
	7	39	35	90
	8	38	34	89
V Nov. 10, 1916	1	34	0	0
	2	26	22	85
	8	31	31	100
	9	38	38	100
VI June 13, 1917	1	8	0	0
	2	17	9	53
	8	12	6	50
	9	72	34	47

of inoculum for the infection of bean seedlings. Apparently soil that is devoid of affected bean tissue cannot serve as a source of inoculum for more than two or three months, or is not an important factor in bringing about infection even though a few spores may live over winter in it.

In order to determine whether old affected vines and pods can serve as a source of inoculum under conditions prevailing out of doors at planting time in the spring, Davis White Wax beans were planted on June 10, 1916, in clean soil in the disease garden; that is to say, in soil in which beans had not been grown since 1911, at which time they were badly affected with anthracnose. Four rows, with forty hills to a row and five seeds to a hill, were planted in the following manner and with the following results (recorded June 26):

Row 1. Seed spotted with anthracnose planted. No mulch used. Only fifteen plants in six hills were alive, all of which showed affection with anthracnose.

Row 2. Clean seed planted, and hills mulched by placing over each a handful of old affected vines left outdoors in a pile over winter. One hundred and sixty-five plants appeared, every one affected on stem or leaves or both.

Row 3. Clean seed planted, and hills mulched by placing over each a handful of old affected vines kept dry in seed house. One hundred and seventy-one plants appeared, every one affected on stem or leaves or both.

Row 4. Clean seed planted. No mulch used. This row was about a rod north of the others. One hundred and sixty-nine plants appeared, on which no infection was observed at this time.

The weather from June 10 to June 15 was clear and warm most of the time and was favorable for seed germination. From the evening of June 15 to June 21 inclusive it was cool and rainy or cloudy, weather very favorable for infection to take place. From June 22 to June 26 inclusive it was clear and warm.

These results plainly indicate that under favorable conditions in the field, affected bean pods and vines from the crop of two preceding years can serve as a source of inoculum when they come into contact with seedlings of a susceptible variety of beans. Nevertheless it is probable that but little infection takes place from contaminated soil or from overwintered vines that are plowed under in preparing the land. In these experiments special pains were taken to place a considerable amount of badly affected

bean tissue where it would be in continued contact with the seedlings. In ordinary practice this would occur only accidentally if at all. But when considerable wet weather follows planting, infection may be expected to occur from contact with old affected vines spread with manure on the surface of the soil after plowing, or from such affected vines as come to the surface after having been plowed under.

Muncie (1917:15-21) carried on tests to determine whether the bean-anthracnose and bean-blight organisms are able to winter over in old bean trash containing affected vines or as spores in the soil. He observed during the summer a small amount of anthracnose on the plants grown in pots where spores had overwintered and where old anthracnose-spotted vines of the second as well as the next preceding year had overwintered. A greater number of plants became affected with blight in these trials. From these data Muncie is convinced that the causal organism of both anthracnose and blight can live over winter in the soil in diseased bean trash and as spores or bacteria in the soil, and infect the crop of the following season. His field observations of preceding years doubtless strengthen this opinion.

Schaffnit (1920) obtained spores with unimpaired germination up to February 12, 1920, from pods of the harvest of the preceding year. Meyer (1910) finds the first appearance of the disease always on plants growing on damp ground directly where fresh stable manure has been applied but not where commercial fertilizers have been used. Pfeiffer (1910), however, believes the organism does not come from manure, as he has observed the disease commonly on land that never receives it. Muncie (1917:21) records inoculations made with an inoculum consisting of dung from a cow fed with bean straw infected by *C. lindemuthianum* and *Bacterium phaseoli*, but states that he was unable in this way to produce anthracnose and that blight appeared on only one plant. It is not unlikely that beans planted on heavily manured ground would produce so rank a growth that moisture conditions about them would be more favorable for infection than with plants not so vigorous. It is also possible for the pathogene to be introduced into a field with manure having infected bean straw mixed with it.

Further infection of the plant and spread of the disease through the field

The inoculation of the leaves, the petioles, the branches, and the inflorescence of the older plants occurs in the same manner as that of

the seedlings. The plants, being larger, are more likely to be in contact with one another and thus make easier the transmission of the spores. If the vines have a tendency to hang low and be bushy, the air beneath them remains sufficiently humid for spore germination for a longer time after rains and dews than does the air outside. During rains the drops of water on the plant run together and move over the surface, in some places dripping from the leaf apices to other leaves and vines, in other places running down the stem or falling in large drops on the pods, where they spread out over the surface as they strike. When wind accompanies a storm, the wet leaves are blown against one another, against the leaves and stems of other plants, or to the ground. If a plant is affected with anthracnose, multitudinous spores from the various lesions become suspended in the rain water and are carried as described to the healthy parts of the plant. The pods become inoculated in this manner and in other ways.

When falling raindrops strike a spore-producing lesion or a film of water anywhere containing spores, drops of the contaminated water are spattered to the near-by stems and leaves. Faulwetter (1917), in his efforts to explain the rapid dissemination of *Bacterium malvacearum*, has made some interesting experiments to determine the distance to which water can be splashed by falling drops of various sizes. He finds that splashing occurs only when drops fall on a film of water, and that it is the water of the film that is splashed. A drop 0.1 cubic centimeter in volume falling 16 feet onto a film over a glass plate spattered water as far as 64 inches. A drop 0.02 cubic centimeter in volume falling 16 feet during a wind of 10 miles an hour "splashed water in abundance a distance of 8 feet.....in moderate quantities as far as 12 feet..... and in slight amounts to 16 feet." He concludes that the possibilities of dissemination of bacteria in suspension in film water on cotton leaves " are considerable if one includes the distance bacteria may be carried from the original lesion, then splashed up again and carried farther, and so on, until a dilution too great for infection is obtained."

In addition to being splashed from contact with falling raindrops, contaminated drops of water may be carried bodily during a heavy wind to healthy parts of the plant, and plants blowing against one another will aid in disseminating the spores. Persons, as well as dogs, rabbits,

pheasants, and other animals, passing through the field when the plants are wet, may serve to carry the spores from one plant to another. Insects, although minor agents, no doubt aid in inoculating healthy plants.

Gardner (1918:34) has shown conclusively that after a rain the spores of *Colletotrichum lagenarium* are present in the soil beneath affected plants, and that they may be disseminated by the spattering of such soil during a rainstorm. He has shown also that spores may be carried across a field in surface water during storms and washed or spattered onto healthy plants, infecting them and thus greatly enlarging the foci of infection.

No field observations of the spread of the bean-anthracnose disease were made during the three years when the writer's field work was done, since the disease appeared to only a slight extent during that time. What has been said regarding the spattering of contaminated water and soil in the dissemination of the two diseases mentioned would seem to be true in the case of *C. lindemuthianum*. Certainly the similarity of this organism and *C. lagenarium* in the matters of spore production, character of spores, and method of infection, would lead to the conclusion that the means of dissemination and inoculation shown in the case of the cucumber-anthracnose organism would exist also in the case of the bean-anthracnose fungus.

Infection of seeds

The appearance and extent of the canker on the seed, and its progress from pod to seed, are described on pages 107 and 111. As the pod matures, the seeds within prepare for a resting period. The cells, now packed with reserve food, become denser, drier, and more capable of resisting decay. The mycelium of the fungus within the cells of the seed also becomes less active, and possibly entirely dormant. It renews its growth, however, at conditions of temperature and humidity to which the embryo of the seed responds but slowly. There is probably very little activity of the fungus in seed stored in a dry place. Halsted (1892:285) and others report having found viable spores on and within spotted seed stored in such a place, and the writer has often so found them. The acervuli were black and dry, and it was not ascertained whether spores were being produced under such conditions or whether they were produced earlier

when the seed was in a more moist condition. Just how long the fungus can live in old seeds has not been determined, although cultures were obtained from seeds two years old.

Infection studies

Susceptibility of plants of different ages to infection

But little evidence has been presented by investigators concerning the susceptibility of plants of different ages to infection. Frank (1883 a: 34) and others find that young and half-grown pods are more susceptible than older ones. Edgerton (1908: 397) remarks that the young bean plant is not readily infected, but his later work (1910: 41) indicates that he had but little trouble in securing infection on seedlings. Cook and Taubenhaus (1912: 49), noting a correlation in this first statement of Edgerton's with results which they had obtained on young fruits of apple and pear with several Gloeosporia attributed by them to the presence of an enzyme capable of forming a tannin-like body toxic to fungi, tested the oxidizing power of the enzyme present in the bean plant at various stages of its development and found that the oxidizing power is greatest in the young bean plant, is small during blossoming and the formation of young pods, is large again when the plants have large green pods, and decreases again when the pods are yellow. After making numerous inoculations on plants at all stages of growth, the writer is convinced that a young bean plant is more susceptible than an older one, and that young parts are more susceptible than older parts. An experiment was made in 1910 in which Refugee Wax beans were planted at intervals of seven and eight days throughout the season, beginning on June 27 and ending on August 22. In the evening of August 31, three days after the beans last planted appeared, all plantings were inoculated by spraying a suspension of spores over all parts of the plants. During the following day the plants were protected as far as possible from drying out by placing wooden boxes over the hills. When observed six days later, all the seedlings were badly infected and some were dying. Good infection was obtained on the younger leaves and petioles of beans planted one month earlier, but slight infection on the older leaves. Those planted two months earlier and having some mature pods were only slightly affected on leaves and vines, but good infection was obtained on young pods. The nearly mature pods showed no evidence of infection. The writer has always obtained

good infection on pods of susceptible varieties when inoculated under favorable conditions for infection before they passed their brittle, or "snap," condition.

Susceptibility of different parts of the plant to infection

As mentioned in the preceding paragraph, Frank (1883 a) says that young bean pods are more subject to attack than are older pods, and this has been noted also by other early writers. Frank further found the pods to be more susceptible than the stems, the leaves, and the petioles, although inoculation on young bush beans resulted in the appearance of lesions on the hypocotyl, the epicotyl, and the veins of young leaves. He found the cotyledons especially susceptible. Scribner (1888) states that parts of the plant other than the pods and the seeds are rarely attacked. Edgerton (1910:42) found that when bean seeds were inoculated with spores of the fig- and the cotton-anthracnose fungi, these organisms were able to attack and grow in the semi-living cotyledons but did not infect other parts of the plants. However, the cotyledons are to be regarded rather as culture media than as host tissue. Lauritzen (1919:33) says the secondary leaves of the bean are more pubescent and seem to be affected more easily at the limiting humidities. This seems to be due to favorable humidity rather than to susceptibility. Others, in writing on the subject, have usually described the disease as occurring on the leaves, the stems, the pods, the seeds, and the cotyledons. The writer has found all young parts of the plant, including the roots, subject to attack, but as they become older they grow more resistant. The tissues of the seedling and of the young pod appear to be the most susceptible. The epicotyl of young bean plants of varieties showing marked resistance to the disease has often become affected when the plant was inoculated, although the other parts showed no lesions. In such cases, resistance may be due to the inability of the infection tube to penetrate the cuticle.

Susceptibility of different varieties of Phaseolus vulgaris L. to infection

In a number of the treatises on bean anthracnose, certain varieties are mentioned as being more susceptible to the disease than other varieties, but in most cases no inoculation experiments have been conducted to confirm these statements. Frank (1883 b:511) says that Lindemuth observed the disease on the red-mottled Zucker-Stangenbohnen while other

varieties near by were not affected, but a few years later he found many varieties susceptible. Trelease (1885), in speaking of the "peculiar susceptibility of the white-podded bean," says that "it is not improbably connected with the delicacy of its tissues, which selection has produced." Scribner (1888) states that wax, or butter, beans — those having yellow pods — are the kind most subject to attack, and later (1889) finds that no variety is exempt, not even those with green pods. McCarthy (1892: 14) says that wax varieties are especially susceptible. Harvey (1894) finds the disease worse on white-podded bush and pole beans. Cobb (1894:379) says that all varieties of *Phaseolus vulgaris* are attacked, though the tenderness of the wax (or butter) beans makes them more susceptible. Halsted (1898:312), after growing six varieties of beans, finds Green Flageolet the most susceptible to anthracnose and blight. Whetzel (1906) states that probably all the "rust-proof" varieties placed on the market will spot under conditions most favorable to the fungus. Tracy (1907), in his notes on varieties, records considerable variation in their susceptibility to anthracnose. Jarvis (1908:162) finds that, while wax-podded varieties are more susceptible, some desirable green-podded beans also are affected. Edgerton (1910:49) finds a number of wax varieties with which he has been working to be very susceptible. He finds Valentine somewhat resistant, and Nox All highly resistant on leaves and stems; and he speaks of Hodson Wax as having a reputation among growers for resistance, although he finds it somewhat susceptible. He thinks that observations of the amount of anthracnose on different varieties growing side by side is of little value in determining their resistance, and believes that the only way to test their resistance in a satisfactory manner is to inoculate each variety with the spores of the fungus. Ferraris (1913) lists a few very susceptible and a few resistant Italian varieties.

The writer (Barrus, 1911) has inoculated a large number of varieties of *Phaseolus vulgaris*. At the time when that work was done, no variety tried proved entirely immune to all cultures. However, it was discovered that there are at least two forms or strains of the organism physiologically different from each other although morphologically and culturally alike. Certain varieties of beans resistant to one of the strains were susceptible to the other, and those resistant to the latter strain were often susceptible to the former. There were other varieties that

were susceptible to all strains, but none were found that were resistant to all. Edgerton and Moreland (1916) inoculated twelve varieties of *P. vulgaris* with cultures of the pathogene from eleven sources and obtained somewhat similar results. The snap varieties generally were susceptible to all cultures, while the Scarlet Runner and a variety which these authors call "Large White Kidney" were resistant to all. Three distinct types of cultures were found among those tried: one able to infect all varieties except the two mentioned; a second that affected the Boston Pea and snap beans but was not able to affect the Red Kidney to any extent; and a third that brought severe infection to the Red Kidney, moderate infection to the snap beans, but only slight infection to the Boston Pea. Fischer (1919:254) records the observations of several German writers concerning the comparative resistance of the different varieties grown in Germany. Some are inclined to think that the wax varieties are more susceptible, others that green snap beans are. Several have observed that pole varieties are more resistant than bush beans, but Fischer says the greater freedom of the former from anthracnose is due to their position on poles, where the conditions are not so favorable for infection as with vines near the ground. He is inclined to believe that the contradictory observations show the existence of different strains of the organism in the various localities. These observations, and those made by him on twenty varieties planted so as to become infected from spotted seed planted among them, lead him to believe that there is no variety in Germany resistant to anthracnose at all times and under all conditions. The most resistant variety of all appears to be Ideal Wachs-Buschbohne. Schaffnit (1920) observed the relative degree of infection on forty-five varieties of beans during 1914 and 1915 at six different localities in Germany, and lists a number of German varieties under each of the following headings: least attacked, moderately attacked, badly attacked. In general he found that varieties descended from the stem "Flageolet" are the most affected, while those descended from Hinrichs Riesen are the least affected; also, that pole beans show much greater resistance than do bush beans. This suggested to him the possibility of crossing pole and bush beans in order to obtain a resistant bush variety. This work he had not completed at the time when he prepared his paper.

The writer (Barrus, 1918) reports the results of a large number of inoculations made on many varieties of *P. vulgaris* and of other beans,

with cultures from fifteen different sources. These for the most part fell into two physiological forms or strains, which are designated, respectively, as *alpha* and *beta*. The varieties of beans, from their behavior when inoculated with these strains, showed a classification into four groups, as follows: ab, those susceptible to either strain of the pathogene; Ab, those resistant to *alpha* but susceptible to *beta*; aB, those susceptible to *alpha* but resistant to *beta*; and AB, those showing resistance to both *alpha* and *beta*. In the first-named group, ab, belong 80 per cent of the wax bush varieties inoculated, 50 per cent of the green-pod bush, 40 per cent of the wax pole beans, and 30 per cent of the green-pod pole beans. It appears from this, then, that the wax bush beans are, generally speaking, the most susceptible to anthracnose. Five varieties are placed in the resistant group AB, but of these only one, Wells' Red Kidney, has shown a satisfactory resistance under all conditions. The writer (Barrus, 1915) described this strain of Red Kidney as having been selected by a farmer as a single healthy individual from a field where all other Red Kidneys were badly affected. This strain has continued to show the same resistance in the many inoculations made by the writer and by other investigators. It is not a pure type, however, the seed varying somewhat in size, shape, and color, and individuals appear from time to time which show some susceptibility to anthracnose, varying from slight to considerable. In a later paper (1918:602) the writer records the resistance of a field bean called White Imperial to several inoculations made with both strains of the pathogene. Recently, however (in 1921), a field of beans said to be White Imperial, the pods of which were severely affected with anthracnose, was observed. It seems not unlikely that strains of the pathogene exist which are capable of infecting even these varieties.

Burkholder (1918:353) has been able to produce an anthracnose-resistant White Marrow by crossing the ordinary susceptible White Marrow with the resistant Wells' Red Kidney and by subsequent selection of the resistant types. In the same manner, McRostie (1919:141) has also reported crossing the Wells' Red Kidney with the Michigan Robust, a white pea bean, but progress had not been made beyond the F_2 generation at the time of this report. In both of these crosses the character of resistance proved to be dominant, and inoculation of the F_3 generation is necessary in order to determine which individuals are homozygous and which are heterozygous to resistance.

No continued efforts have been made, so far as the writer is aware, to render susceptible bean plants immune to anthracnose by the absorption of toxic substances, as has been attempted with some other plants. The writer has endeavored to obtain a greater degree of susceptibility in bean plants showing considerable resistance to one of the strains of *Colletotrichum lindemuthianum*. Such plants, while yet seedlings, were, just previous to inoculation, (a) kept growing in very dry soil for two weeks, (b) kept in very wet soil for two weeks, (c) injured in various ways. In no case was a greater degree of infection obtained than on plants not so treated. Schaffnit (1920) remarks that a weak condition of plants such as comes from a sudden check in growth, as during a sudden fall in temperature, makes them especially susceptible.

Susceptibility of other species of the genus Phaseolus to infection

The statement has sometimes been made that varieties of *Phaseolus vulgaris* only are susceptible to attack by *Colletotrichum lindemuthianum*. Massee (1898), however, reports the disease as most common on French beans (*Phaseolus vulgaris*) and on Scarlet Runner (*P. multiflorus*), and a few other writers on the subject have recorded it as being severe or as occurring on Scarlet Runner (*P. multiflorus*), possibly quoting from Massee (Saccardo 1898, Collinge 1911, Lind 1913). Allescher and Schnabl (1893) distributed specimens of *Gloeosporium lindemuthianum* on leaves of *Phaseolus multiflorus*. Lakon (1916) says that *P. multiflorus* is practically resistant to rust and above all to anthracnose. Schenk (1917) also says that, although the disease is reported as occurring on Feuerbohnen (*P. multiflorus*) in Holland, he has observed this species to be very resistant when other varieties were badly affected. Fischer (1919:258) saw nothing of the disease worth mentioning on three varieties of *P. multiflorus* — *albiflorus* Lam., *coccineus* Lam., and *bicolor* Arrabida — while pole beans of *P. vulgaris* growing next to them were badly affected. Edgerton (1910:41) reports a slight infection of lima beans (*Phaseolus lunatus* var. Small White Pole), and later (with Moreland, 1916:8) good infection on Fordhook's Bush Lima, very slight infection on Large White Kidney, and no infection on Scarlet Runner when inoculated with spores of *Colletotrichum lindemuthianum*. Lind (1913) records the disease on pods, stems, and leaves of *Phaseolus vulgaris*, *P. compressus*, *P. nanus*, and *P. multiflorus*. The

specific name *nanus*, however, refers to the bush forms of *P. vulgaris*, and the name *compressus* to another classification of varieties now included in *P. vulgaris*.

The writer has reported (Barrus, 1918:610) some good infections from inoculations made at various times during several years on the leaves of a number of varieties, both pole and dwarf, of *Phaseolus lunatus* L., both the small, or sieva, lima and the large lima. Fair infections were obtained on the stems, and also, from field inoculations, fair to good infections on the pods (fig. 15). From inoculations made at various times, the varieties Scarlet Runner and White Dutch Runner, of *P. multiflorus* Willd., have shown slight to fair infection on leaves and pods; the latter variety especially showed fair infections on pods (fig. 16) and seeds. The tepary bean, *P. acutifolius* var. *latifolius* G. F. Freeman, has always become badly affected when inoculated in the seedling stage.

The article just cited reports also the results of inoculations made on from one to several varieties of a number of species of Phaseolus supplied by E. V. Piper, of the United States Department of Agriculture. Slight infection was obtained on *Phaseolus aureus* Roxb., but on *P. aconitifolius* Jacq., *P. angularis* (Willd.) W. F. Wight, *P. calcaratus* Roxb., *P. mungo* L., *P. semierectus* L., and *P. sublobatus*, no definite infection resulted.

Susceptibility of plants of other genera and families to infection

Frank (1883 b:518) obtained no infection on cucumbers which he inoculated with anthracnose. Scribner (1888:362) states that the fungus attacks watermelon rinds as well as beans. Farlow and Seymour (1888) and Saccardo (1898:316) record it as occurring on *Citrullus vulgaris* Schrad. Galloway (1889) ascribes the disease "melon rust" to *Gloeosporium lindemuthianum* Sacc. & Magn. Halsted (1893 b:327, 329) obtained infection, from beans, on detached fruits of eggplant, pear, citron, pepper, and persimmon, and he believes (page 333 of reference cited) that the three solanaceous plants, tomato, eggplant, and pepper, are preyed upon by the same *Colletotrichum lindemuthianum* which causes a pod spot of the bean. Stoneman (1898:93) points out that inoculations made on detached fruits placed under a bell jar cannot be depended on, as such fruits are much less resistant to attack than are fruits under normal conditions, and are more in the nature of culture media. Smith (1904:28) obtained good infection from inoculations made on bean, but none on cucumber,

FIG. 15. ANTHRACNOSE ON PODS OF PHASEOLUS LUNATUS, LIMA BEAN

pumpkin, squash, watermelon, and muskmelon. Cook and Taubenhaus (1912:22, 27) obtained only negative results from inoculations of young

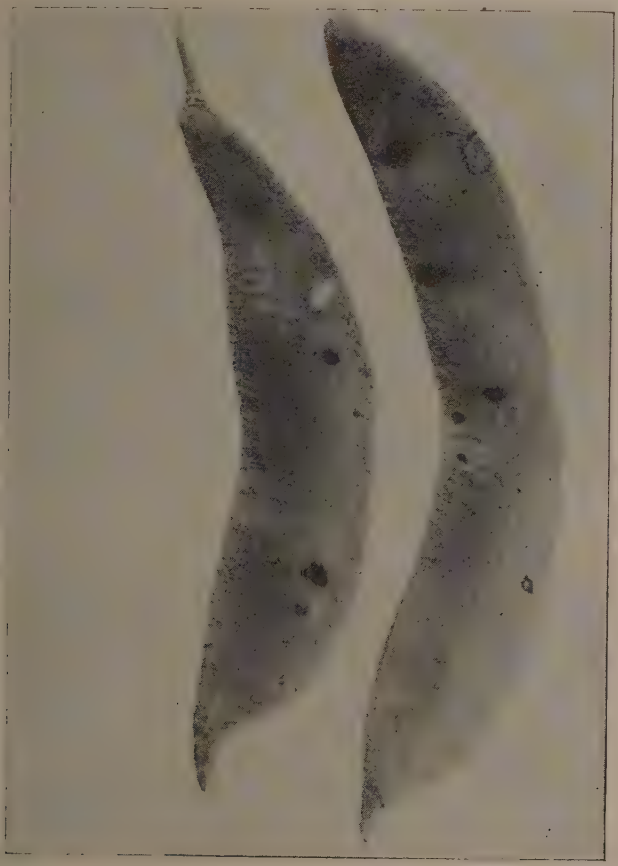

FIG. 16. ANTHRACNOSE ON PODS OF PHASEOLUS MULTIFLORUS VAR. WHITE DUTCH RUNNER, PRODUCED BY ARTIFICIAL INOCULATION MADE ONE MONTH BEFORE PHOTOGRAPH WAS TAKEN

and ripe apples and pears with *C. lindemuthianum*. Edgerton (1911:8) also was unable to infect apples with this organism from inoculations

which he made on picked fruit kept in a moist chamber. He was unsuccessful also in his attempts to infect the leaves, stems, and fruit of cucumbers with this fungus (Edgerton, 1910: 41). Shear and Wood (1913: 78) inoculated fruit of apple, young wax bean pods, young cotton bolls, a mature pumpkin, a mature squash, green tomato fruits, and a nearly mature watermelon, with the conidia of the bean-anthracnose fungus, punctures being made in all except the bean pod, in which case the spores were applied to the surface; but in no case, not even with the beans, was infection obtained. It is possible that the beans inoculated were resistant to the strain of the pathogene employed. Krüger (1913: 294) inoculated beans and cucumber fruits kept under the same bell jar, getting good infection on the beans but none on the cucumber even when it was injured, and he concludes from this that the forms occurring on the two plants are different. Inoculations which he made on apples, bananas, and tomatoes were unsuccessful on the first two, although they resulted in a whitened, sunken, spore-producing area about the punctures.

Chester (1894) reports that many seedlings of cowpea (*Vigna sinensis* Endl.) of the Conch variety died as a result of an attack of anthracnose caused by *Colletotrichum lindemuthianum*, and an examination of the seed showed that 9.5 per cent were diseased. McCarthy (1894: 151) reports that pods of cowpeas nearly full-grown were occasionally attacked by a species of Gloeosporium. Butler (1918: 262) reports an anthracnose on cowpea in India, saying that in general its characters agree with that of the bean but that experimental work is necessary before the two diseases can be pronounced identical. He records also (page 267 of reference cited) an anthracnose on val (*Dolichos lablab* L.) and on kulthi (*D. biflorus* L.), and tentatively refers the causal pathogene to *Glomerella lindemuthianum* (Sacc. & Magn.) Shear.

Sydow (1886) distributed what appear to be diseased pea pods (labeled *Vicia sativa*) under the name *Gloeosporium lindemuthianum*. Viala and Pacottet (1905) refer to *Colletotrichum lindemuthianum* as the fungus causing anthracnose of peas and beans, and Cooke (1906) reports it as being the cause of a disease of peas as well as of French beans. Other writers have not reported it on peas, and Edgerton (1910: 41) could not secure infection from inoculations made on garden peas even after the wax was rubbed off the leaves. Fischer (1919: 259) says that both Lemke and Feldt report having observed plants of *Vicia faba* severely attacked

by this fungus, but his own observations do not confirm this and he thinks the disease observed was due to some other fungus.

Edgerton (1910:40) also sprayed spores of *C. lindemuthianum* on young bush beans, alfalfa, and cotton plants protected by bell jars, but obtained infection on the beans alone. Bäumler (1888) reports *Gloeosporium lindemuthianum* as occurring on stems and leaves of *Orobus vernus*. It seems that in this case the species of the pathogene was incorrcetly determined.

The writer, in the course of his infection studies with beans, has inoculated seedlings of sweet pea (*Lathyrus odoratus* L.) and garden pea (*Pisum sativum* L.), vines and young pods of cowpea (*Vigna sinensis* [L.] Endl.), and young plants of mandrake (*Podophyllum peltatum* L.), with spores of *Colletotrichum lindemuthianum*. Excellent infection was obtained on beans used as checks, but the other plants remained free from disease. In a series of other inoculation experiments on seedling plants, fair to good infection resulted on the stems of certain individual black-eyed beans or cowpeas (*Vigna sinensis* [L.] Endl.), and slight to fair infection on the epicotyl of the kulthi bean (*Dolichos biflorus* L.); but no infection resulted on any part of the bonavist bean (*Dolichos lablab* L.), the guar bean (*Cyamopsis tetragonoloba* Taub.), the asparagus bean (*Dolichos sesquipedalis* L.), the jack bean (*Canavalia ensiformis* [D.] DC.), four varieties of horse bean (*Vicia faba* L.), and the garbanzo bean, or chickpea (*Cicer arietinum* L.). There are evidently but few species outside the genus Phaseolus which are susceptible in any degree to anthracnose, and no plants except varieties of *Phaseolus vulgaris* are susceptible to such an extent that the disease becomes epiphytotic in regions where such plants are extensively grown. It is not unlikely that several strains of the pathogene exist, one capable of infecting *Phaseolus multiflorus* or some of its varieties in a severe manner, another able to attack *Vigna sinensis*, and others attacking plants related to the bean, each being confined rather closely to the species, or even to certain varieties within the species, to which they have adapted themselves.

Susceptibility of Phaseolus vulgaris to infection from other anthracnose fungi

Frank (1883 b:518) was the first to inoculate the bean with spores of another anthracnose fungus in order to determine whether the forms occurring on different hosts were really the same species. He sowed

on green bean pods the spores of *Gloeosporium castagna* Mont., which had proved to be very virulent on the leaves of the silver poplar, but obtained no infection. He therefore concluded that gloeosporial forms are independent species and have their own host plants. Southworth (1890:48) attempted unsuccessfully to infect bean pods with the hollyhock-anthracnose fungus, *Colletotrichum althaeae* Southw. (*C. malvarum* [A. Br. & Casp.] Southw.), but was successful with *C. lindemuthianum*. Halsted (1893 b:327, 329), in connection with his cross-inoculation work, obtained good infection on detached bean pods with *Colletotrichum* sp. from the eggplant, and with Gloeosporia from pepper, apple, and tomato; also (1893 d: 248) with *Colletotrichum lagernarium* (Pass.) E. & Hals. from the watermelon. Sheldon (1904:132-135) inoculated wax-bean seedlings, bean plants in blossom, and bean pods on the plants, and also six different cucurbits, with spores of *C. lagernarium* from pure cultures obtained from a watermelon fruit. Infection was obtained on the cucurbits in most cases, but the beans for the most part were free from evidence of infection. Sheldon did find, however, spots bearing spores both on the beans inoculated by him and on those used as checks. He decides that it is not safe to conclude from his results that the anthracnose fungus on the beans is the same as that on the melons and the gourds. Edgerton (1910:41) obtained no infection on young bush beans sprayed with spores of the fig anthracnose (*Glomerella fructigena* [Clinton] Sacc.) and of the pepper anthracnose (*G. piperata* [E. & E.] S. & S.), and no infection on freshly picked bean pods placed in a moist chamber and inoculated with a culture of the rose-anthracnose fungus (*Gloeosporium rosae* Hals.); although in every case good infection was obtained with the bean-anthracnose fungus on the beans used as a control. Bean seeds wet with a suspension of spores of the fig- and the cotton-anthracnose fungus were somewhat infected. Spores of the fig-anthracnose fungus were being produced in abundance on seed that had rotted in the ground, and the semi-living cotyledons of the germinating beans were attacked by both fungi. The spots did not develop further, however, while in the case of seeds treated in the same way with spores of the bean-anthracnose fungus the cotyledons, and later the plants, became highly infected. Taubenhaus (1911:198) reports success in obtaining infection on pods of pole and bush lima beans in the field from puncture inoculation with spores of species of Gloeosporium from sweet pea, apple, and mandrake, or may-apple, and with

Gloeosporium officinale E. & E. from sassafras, *G. gallarum* Ch. Rich. from oak gall, and *G. psidii* Del. from guava. The disease produced, except in the last-named case, resembled sweet-pea anthracnose but did not resemble the bean disease. Shear and Wood (1913:77–89) inoculated detached bean pods with anthracnose conidia from avocado, cotton, guava, loquat, mandarin, orange, pitcairnia, and privet, but in the case of none of these did they obtain any infection. Krüger (1913) inoculated detached bean pods kept under bell jars with conidia of gloeosporial forms from apple, banana, and tomato, and, while good infection was obtained on checks consisting of detached fruits of the respective hosts, the result on bean pods was doubtful; no infection was obtained on the uninjured pods, although there was some mycelial growth in the tissue surrounding the injury made on other pods. Gardner (1918:23) inoculated five varieties of beans with *Colletotrichum lagenarium*, with negative results.

On inoculating bean seedlings of several varieties with spores of the anthracnose fungus from sweet pea and from mandrake, the writer did not obtain any infection. Fair infection was obtained on sweet-pea seedlings inoculated with spores of the form from sweet pea, and on the leaves and stems of young mandrake plants growing in the woods and of those transplanted to the greenhouse inoculated with the form from mandrake. From his own results and from those obtained by others, the writer is inclined to believe that, in general, each of the various anthracnose fungi is confined to its own host or to closely related plants.

ECOLOGIC ASPECTS

In the preceding discussion frequent reference has been made to weather conditions favorable to infection. There is no question that the weather is an important factor in the growth of this fungus, just as it is in the growth of higher plants. The fungus has its ups and downs according as the season is wet or dry. Temperature and humidity are the two factors of greatest importance, and of these the latter is usually the controlling one in the Northern States. This has been generally recognized by growers, and its significance in the development of the disease has been pointed out in some of the earlier accounts.

Edgerton (1910:28, and 1915:248) has shown that temperature is the controlling factor under conditions in Louisiana. The disease, while

prevalent during the cooler part of the growing season, is absent from the fields there during the hot months of June, July, and August, even with ample rainfall and when diseased seed was used for planting. Furthermore, Edgerton experienced great difficulty in keeping cultures of the organism alive during the summer. The writer has never had any difficulty in obtaining infections from inoculations made during the summer, although for the success of the experiments he has made them at times when the conditions promised to be most favorable. Some of the inoculations were made in the greenhouse when the temperature during the following days ran high, and yet fair to good infection was obtained in several instances. Cultures of the fungus in the laboratory grow very slowly or not at all during the excessively warm weather of the summer, and in some cases they die when not transferred frequently. When placed in a cellar where the temperature remained at about 16° to 20° C., a good growth of mycelium and abundant production of spores resulted. During the summer season in the North, the periods of excessively high temperatures are short. The high temperature of the day is not sufficient to kill the fungus in the host, and growth and spore production may take place during the lower temperatures of the night. The effect of temperature on growth of the fungus in culture media has already been discussed (page 121). Lauritzen (1919:20), by employing inoculation chambers where temperature and humidity were controlled, determined the range of temperatures at which infection of bean seedlings takes place after inoculation with *Colletotrichum lindemuthianum*, when kept at a favorable constant degree of humidity, to be from 57° to 80° F. At the extremes the number of infections occurring are small, but they are more abundant at the more nearly optimum temperatures, as one would expect. Lauritzen says that the data point to a lower temperature limit for infection when forty-eight hours are used for the infection period than when twenty-four hours are used.

Moisture must be present or the humidity of the air high if the fungus is to gain entrance to the host. Lauritzen (1919:29) found that infection took place at humidities of 95.8 and above when the temperature was kept at from 65° to 68° F. It was not necessary that a film of moisture be kept on the leaf during the germination of the spore, for infection occurred when the plants were dried off after inoculation and before being placed in the inoculation chamber. Lauritzen did not determine how

the spore gets sufficient water in such cases to permit germination, but he suggests that when the evaporation is not too great it may absorb water from the host plant by imbibition and later by osmosis.

If the soil is wet and cold, the bean seed germinates slowly, but the spores of the fungus when present on the seed under such conditions will germinate and penetrate the host before it appears above ground. If dry weather follows the appearance of the plants grown from spotted seed and infection has not yet taken place, the chances are good that the spotted cotyledons will drop off before any infection occurs. When this happens the plants are as free from infection as though they had come from healthy seed, but the affected cotyledons on the ground may serve as a source of inoculum for a time. Often after wet weather the juvenile leaves of the seedlings become very badly spotted. These in turn drop off, and if the plant has not been infected otherwise it may continue to develop entirely free of the disease (fig. 17). If, on the other hand, rainy weather should occur following the germination of spotted seed and before the cotyledons fall, some of the seedlings will surely become infected and the disease will be likely to spread to neighboring plants. In fact, an instance is known in which, of two fields planted from the same lot of seed but at different times, one field became badly diseased and the other remained healthy because rainy weather succeeded the planting of the one and dry weather the planting of the other.

If infection is to take place in plants inoculated with the spores of the fungus, a moist condition must prevail for at least eighteen consecutive hours at some time before the spores succumb to desiccation so that they may germinate and form appressoria. This statement is based on spore-germination tests recorded earlier (page 117). In the inoculation experiments conducted by the writer, the plants were usually kept in an inoculation chamber for about forty-eight hours, although successful results were obtained when they were left for but twenty-four hours. That the spores may endure a period of dryness before favorable conditions arrive was shown by an experiment in which seedlings growing outdoors were inoculated during the morning of a bright, hot day. The next morning, before the dew had evaporated, each plant was covered with a shaded lamp chimney plugged with cotton at the upper end. All these plants showed lesions after six days.

FIG. 17. BEAN PLANT FROM SPOTTED SEED, THE JUVENILE LEAVES AND STEM OF WHICH BECAME AFFECTED WITH ANTHRACNOSE BUT WHICH PRODUCED A CLEAN CROP OF PODS BECAUSE DRY WEATHER PREVAILED DURING THE SUMMER

(Transplanted to a pot for photographing)

A rainy period of several days accompanied by cool weather is the most favorable condition for infection and for the development of the fungus. Night dew or even humid air, however, is sufficient to allow infection to take place. Conditions permitting the plant to retain moisture beneath the vines are particularly favorable for the infection of the pods. Such conditions are afforded by poor soil drainage, or especially by poor air drainage such as may come about from a bushy growth of vines and from plants growing close together; and similar conditions may exist in a low area or pocket in the field.

Beans grown at the time of the year when the prevailing weather conditions are the least likely to be favorable for infection, will of course be the freest from anthracnose. Plants inoculated artificially during a rainy day will become badly diseased, while plants in neighboring hills in the same row will be but slightly affected and hills farther on not at all. This is because the weather has remained comparatively dry from the time of inoculation until the pods were maturing, and thus spore dissemination was prevented. The disease does not spread as readily through a field planted in check rows as through one planted in drills. Corbett (1907) says that growers of field beans find the disease worse on crops planted early. In New York State late-maturing beans are the most liable to damage from anthracnose, as weather conditions favorable for infection commonly occur during September. For this reason an early-maturing variety planted early would have a better chance of escaping infection, other things being equal, than a late-maturing one.

These facts explain why the disease materially decreased during the dry seasons of the four years from 1907 to 1910, and why it has been so severe during years of abundant rainfall. The seed produced in dry seasons is practically free from the disease, and when such seed is used the plants resulting therefrom are remarkably free from anthracnose, even though the season may be wet, because the source of infection is not present. After a season or so of rainy weather, however, the disease, at first inconspicuous, may become general throughout the field and a large amount of spotted seed may result. It has been claimed by seedsmen that in certain irrigated sections of the West where there is but little rainfall during the growing season, plants free from the disease can be grown from spotted seed; but it is questionable whether the moist conditions beneath the vines resulting from irrigation would not be sufficiently

favorable for infection occasionally to take place, at least when spotted seed is planted. The disease is occasionally reported from such sections. Complete freedom from anthracnose may be expected in those regions where dry farming is practiced. Lauritzen (1919:32) suggests that the variation in the amount of moisture in the air in different regions may be an important factor in the distribution of diseases over the earth's surface.

PROPHYLACTIC ASPECTS

As early as 1893 a number of measures for the control of bean anthracnose had been recommended. Among these were such as treating seed with chemicals or hot water, selecting seed from healthy plants, spraying with bordeaux mixture and other substances, working among the plants only when they are dry, planting exclusively on ground that has not produced diseased plants the year before, and selecting a dry, airy situation with light soil. These recommendations, if carefully followed, will usually result in the production of plants free from anthracnose. Doubt has been cast, however, on the efficacy of certain of these recommendations, and it is worth while to consider the advantages and disadvantages of the various methods.

Seed disinfection

Seed treatment was first recommended by Halsted (1892:286), who at that time used ammoniacal copper carbonate. Later (Halsted and Kelsey, 1895:30) he tried full-, half-, and quarter-strength bordeaux mixture, and concluded that such treatment had but little effect in killing the mycelium within the seed. Beach (1892:320), after experimenting with hot water, bordeaux, ammoniacal copper carbonate, and potassium sulfide, found that, while hot-water treatment resulted in the lowest percentage of plants with anthracnose, the untreated seed gave a greater quantity of marketable beans because of the better stand, and that even with severe treatment, enough disease remained to injure the crop. Craig (1893), after soaking seed for varying lengths of time in solutions of different strengths of ammoniacal copper carbonate and copper sulfate, concluded that seed can be treated cheaply and advantageously with copper compounds, preferably ammoniacal copper carbonate. The best result he obtained, however, was but 79 per cent of healthy plants, and but 73 per cent of the treated seed germinated. Later (1898) he experimented with lysol,

formalin, potassium sulfide, nitrate of soda, corrosive sublimate, and kainit. The lysol treatment resulted in 4 per cent of diseased pods, in comparison with 57 per cent in the check row. The value of other treatments are in the order named, corrosive sublimate giving 19 per cent of diseased pods and kainit 36 per cent. Bedford (1900) soaked bean seed for two hours in formalin solutions varying from one ounce in one gallon of water to one ounce in four gallons. The former dilution gave the better results, without the germination being affected appreciably. Sevey (1907) states that experiments at Cornell University, in which bean seed was soaked for forty-five minutes in formalin solution 1–200, gave profitable results. Kirk (1905) says that good results have been obtained by soaking seed for five minutes in water at a temperature of 140° F. (60° C.), or for fifteen minutes in water at 130° F. (54.4° C.).

Whetzel (1906) believes seed treatment to be of little practical value in controlling the disease, as such treatment reduces the stand and renders the seeds unfit for planting with a machine unless they are allowed to dry, in which case many of them slip their coats and thus become worthless. Fulton (1908:15) says that he has kept beans for forty-five minutes at 135° F. (57.2° C.) dry heat without appreciable effect on germination, while seeds placed in water during a like exposure are practically all killed. He thought that dry heat might be used as a seed treatment for control of bacterial blight, but experiments that he made to prove this gave negative results. Edgerton (1910:46–48), from experiments he has made, is inclined to believe that the disease may be materially reduced by soaking the seed for from ten to fifteen minutes in water at a temperature of 50° C. (122° F.), and that seeds thus treated will not slip their coats and their germinative ability is not impaired. Later, Edgerton and Moreland (1913) report that the treatment of bean seed with hot water 50° C. for eight minutes, with corrosive sublimate solution 1–1000 for twenty minutes, with benetol solution 1–50 for twenty minutes, or with corrosive sublimate 1–1000 in a 1–50 glycerin solution, did not materially reduce the percentage of germination below that of untreated seed, although formaldehyde solution 1–100 did reduce the germination in the field. However, none of the treatments except hot water had much merit as a control measure for anthracnose, although blight was materially reduced by the treatments with corrosive sublimate and benetol.

Hollman (1915:691) treated seed with 2.5- and 1.25-per-cent Chlorphenolquecksilber, with 1- and 2-per-cent sublimate, with 2.5- and 4-per-cent formalin, with a tar preparation called "Körnerschutz," with petroleum for thirty minutes, and with 2-per-cent copper sulfate, and also with 1-per-cent bordeaux sprayed on the seeds. None of these treatments were effective, the disease being serious in all plots. The Chlorphenolquecksilber seemed to have the effect of stimulating the plants to increased growth, so that they yielded more, in spite of the disease, than did plants in other plots.

Fischer (1919:249) discusses the results obtained by a number of investigators with seed treatment. He says that Appel used 1-per-cent sublimate; Remn and Vasters tried Chlorphenolquecksilber; Wahl tried a new and water-free Chlorphenolquecksilber called "Uspulun"; Weirup experimented with sublimate and later with Uspulun; Schander and Krause treated badly affected seed, which when untreated gave but 19.3 per cent germination, with 1-per-cent sublimate for fifteen minutes, resulting in 29.3 per cent germination; with 0.25-per-cent Chinosol for three hours, resulting in 32 per cent germination; and with 5-per-cent Uspulun for one and one-half hours, resulting in 46 per cent germination. In no case, however, was there a satisfactory control of the disease, which became general throughout all the plots. Even when an entire field at the experiment station was planted with treated seed — in which case infection could not have taken place from near-by plants from untreated seed — the disease appeared just as severely as in fields planted with untreated seed. Fischer concludes from these observations that seed treatment of beans to control anthracnose has no practical value.

Muncie (1917:26–37) treated seed for varying lengths of time with chemicals of varying strengths, and with both dry heat and hot water. The chemicals used were: mercuric chloride and sodium nitrate heated to 55° C. (131° F.) and not heated; mercuric chloride alone; mercuric chloride with oxalic acid; zinc chloride; formaldehyde solution as a dip and sprinkled on seed; formaldehyde gas; copper sulfate with the addition of sulfuric acid; and calcium hypochlorite. Both healthy seed, and seed affected with anthracnose and with blight, were treated, and the effect of the treatment on germination and on the pathogenes was noted. It is seen from the results given that in none of the treatments was either pathogene killed in all the seeds, except in those cases in which the

treatment materially reduced the percentage of germination. Muncie states, in summing up the results of the treatments, that it seems possible to control the disease in a large degree in case of a light infection by employing seed treatments, and that the treatment most efficient is either a thirty-minutes immersion in a 35-per-cent solution of bleaching powder, or a sprinkling of the seed, as in the treatment of oat smut, with a solution of formaldehyde, using 1 pint of formaldehyde to 30 gallons of water. There is not sufficient evidence submitted in his data, however, to admit this possibility. His summary at the end of the bulletin states accurately the conclusions reached, namely, "Seed treatments with chemical solutions and wet and dry heat have failed to control these diseases." Rapp (1920) concludes from his numerous seed-treatment experiments with formaldehyde, mercuric chloride, sulfuric acid, dry heat, and hot water, to control bacterial blight, that no present method can be regarded as satisfactory, since in killing the blight pathogene the germinating power of the seed is either greatly weakened or totally destroyed.

Kidd and West (1918) soaked bean and other seeds for varying lengths of time (from six to seventy-two hours), and found that, while germination was more rapid from soaked than from unsoaked seeds, subsequent growth, particularly of the bean, was poorer — although with horse beans (*Vicia faba*) it was greatly improved. Bean seed was soaked in water at various temperatures, but always the resultant growth was poorer than when dry seed was used. The literature on the subject, however, reviewed by Kidd and West (1919), indicates a better growth and a higher total yield from soaking in a limited quantity of water.

Further experimentation with seed treatment should not be regarded as something bound to be resultless. No one has made a careful study of the permeability of the seed coat of the bean to various disinfecting agencies, nor of the action of these agencies on the fungus within the seed. Seed treatment, to be effective, must destroy the pathogene within the seed, notwithstanding the extent of its growth there, in order that the affected seed may not serve as a source of inoculum. At the same time, the treatment must not injure sound seed. Any treatment, to be of value, must achieve these two conditions, and the problem does not appear to be insurmountable. Nevertheless, healthy seed can be obtained in other ways. The selection of clean seed (page 168) certainly offers a greater promise of success.

Sorting out affected seed

The selection of clean seed has been recommended by many plant pathologists. Frank (1883b:523), after having determined that infection of the seedling can take place from the fungus overwintered in affected seed, was the first person to recommend the use of clean seed by the sorting-out of spotted ones or by the securing of seed from non-infested fields. Beach (1892:323–326) obtained good results by sorting out the affected seed before planting. Gain (1898:200), after experimenting with Mont d'Or, a climbing wax-podded variety with dark brown seeds, states that he is able to discard practically every diseased seed by hand-sorting. He observes that diseased seeds are lighter than healthy ones, and advises growers to discard all light seed. In another article (1899:389) he says that by carefully sorting out infected seed the anthracnose disease can be controlled. Whetzel (1908:432), however, although he used the utmost care to remove every suspected bean, was unable to remove the diseased seed completely from white beans, a germination test of the seed thus sorted showing as many as 12 per cent of the remaining seed diseased. When an attempt is made to sort colored seed, an even larger percentage of diseased seed passes unobserved. Fischer (1919:252) concludes from experiments conducted by Schander and Krause, and from other tests made at Bromberg in 1915 and 1916, that it is not possible to control the disease by this method since many affected seeds cannot be detected from their appearance.

It is, of course, impossible to sort out every affected seed even by the most careful examination. Such seed as are left in may produce affected plants if conditions following planting are favorable for the development of the fungus, and such affected plants may serve as a source of inoculum to other plants in the field. However, as every diseased seed discarded removes one source from the field, it would appear to be preferable to sort the seed carefully before planting rather than not to sort at all. A practical grower of a considerable acreage of beans in northern Vermont says that since he has made a practice of hand-sorting his seed he has had no anthracnose, but that before he did so the disease was harmful.

Selecting seed from clean pods

It has occurred to a number of experimenters that the surest way of obtaining clean seed is to select it from healthy plants or at least from

unspotted pods. Harvey (1894) advises this method, and emphasizes the idea that pods showing any evidence of disease, such as pits, discolored patches, and wrinkled or blistered places, should be rejected. Cobb (1894: 383) recommends hand-picking the seed in the field, selecting only the healthiest-looking pods. Several others since then have recommended the practice. For several years Whetzel (1908:441) grew clean Black Wax beans that were selected from clean pods, and at a time when anthracnose was very prevalent throughout the State. He recommends selecting seed from clean pods, hand-picking them in the field, and resorting them later. He suggests also that seed from the irrigated regions of the West may possibly be free from the disease. A seedsman in an irrigated section of Colorado declares that he has been able to grow clean plants from diseased seed and could continue the practice without danger of the disease appearing in the field.

The writer selected seed from clean pods during four consecutive seasons (1908 to 1911), the purpose being to determine whether such seed would produce anthracnose-free plants with ordinary culture, particularly during a wet season, and whether such a method could be recommended as a general farm practice, Since 1911 he has been unable to carry out these trials further, except in a most limited way.

The seed for these experiments was obtained from pods picked in the field, or in a few cases from the mow. Any seeds showing evidence of anthracnose or blight were rejected. Later the pods were resorted, and, after shelling, the beans also were sorted to remove broken, undersized, or abnormal beans. The seed was then distributed, in lots of about a quart of each variety, to growers and experimenters in this and other States, in order to obtain, in some place at least, good conditions for a test. Those who received the seed were urged to plant it at a distance from other bean patches and to observe the precautions necessary to avoid communication of the disease to this seed patch.

In these tests extending over a period of four years, twenty-four different plots of beans, containing from one to eight varieties, were grown in various parts of New York State and in a few places outside the State. In five of these plots, there was some anthracnose on a few of the varieties. In all but one of these five cases the infection was slight, and in all cases the inoculum came from a source other than the seed.

The chief drawback to the success of the trials was the dry weather which prevailed during the growing season in these years. Beans grown from seed that had not been selected produced anthracnose-free plants in many cases. Plants grown by Dr. Edgerton in Louisiana from healthy seed sent to him were free from anthracnose and with few exceptions free from blight, while other beans grown in the trucking section were badly affected with both anthracnose and blight.

Another factor not given consideration at that time was the resistance of many of these varieties to at least one strain of the pathogene. It was learned later that this is true of the varieties Navy Pea, White Kidney, Red Kidney, Red Marrow, and Blue Pod Medium, and also of Turtle Soup to some extent. In most instances, however, anthracnose had in the past appeared in a destructive manner on the varieties sent for testing, in the localities under consideration.

The introduction of healthy seed of a certain variety into a locality in which the strain of the fungus to which it is susceptible is absent, would of necessity result in an anthracnose-free crop. This may be the reason why clean seed from other sections of the country often produces better yields than does home-grown seed. However, if affected seed of such a variety is introduced into a certain locality, the strain of the pathogene present on the seed, being capable of producing the disease in that variety, will multiply under conditions favorable for it and the entire crop may become diseased. Healthy seed is therefore always safer to use as long as the particular variety is susceptible to any strain of the organism.

In 1914 Professor F. C. Stewart, of Geneva, New York, planted seed that he himself had selected from clean pods. The plants remained healthy all summer and the pods were free from anthracnose when picked. A patch of Red Kidney and Turtle Soup beans selected from seed from clean pods in 1912 was planted at Ithaca at a distance of ten rods from other beans artificially inoculated with the two strains of *Colletotrichum lindemuthianum* during the summer. The plants from clean seed remained free from anthracnose.

In 1915 Bert Smalley, of Interlaken, New York, grew one row, fifteen rods long, of Red Marrow beans from seed selected from clean pods by Professor Stewart and afterward resorted by him in order to be sure there was no anthracnose present. The field in which this row of Red Marrows was grown was not cultivated at all during the season because of wet

weather, and so weeds of various kinds grew up among the bean plants. On October 4 the plants were found to be generally affected with anthracnose. From the row 75 plants were selected, one plant at every pace. On these plants there were 209 pods, of which 137 were affected with anthracnose, 67 were not spotted, and 5 were doubtful. About 40 rods southwest of the end of this row was a large field of Red Kidney beans which were badly affected with anthracnose. It was concluded that the first infection of plants in the row planted with clean seed came from spores carried from the affected Red Kidneys by some animal, and, since the tall weeds about the beans kept them moist most of the time during the rainy season, and since they were planted in drills so that the plants were in contact with one another, the disease readily spread along the entire row.

These trials seem to indicate that the use of clean seed is not altogether successful in producing a crop of beans free from anthracnose unless the season is dry, under which condition there is no loss from the disease in any field. The experiments are reported because the results are such as may be expected in such cases. So far as observations were made in these and in other experiments, clean seed always produced anthracnose-free seedlings in the field, and this is all that can be expected of clean seed. Infection, when present, must have taken place from an inoculum of a source other than the seed. In some cases this came early from old affected vines or from near-by affected plants. Infection will always be likely to occur from such sources under favorable weather conditions unless precautions are taken to prevent it. Since clean seed can be depended upon to produce seedlings free from anthracnose, the question becomes one of deciding whether or not the presence of affected seedlings in the field is a sufficiently great menace to warrant the use of clean seed. The writer, from observations of his own experimental plots and of many fields in which clean seed as compared with affected seed has been used, is convinced that the presence of such affected seedlings is a menace that warrants the grower's going to considerable pains and expense in order to obtain healthy seed. Growers generally will probably prefer to buy clean seed if they can get it, rather than to take the trouble to produce it. But some one must produce it if it is to be had, and the question of production is the one concerned here. It is true that following dry seasons there will be but little difficulty in obtaining

bean seed almost or quite free from anthracnose. But it must be possible to obtain such seed every year if the disease is to be avoided in years favorable for its appearance. The practice of selecting from clean pods is the only reliable way to secure seed free from anthracnose (figs. 18 and 19). The method in its practical application involves the use of a seed plot, on which the selected clean seed is planted. This plot should

FIG. 18. A HILL OF WAX BEANS FROM SPOTTED SEED
The pods are so badly affected with anthracnose that they are worthless

produce the necessary seed for planting the main field the following year. The steps in carrying out the measure are as follows:

1. Selection, in the fall, of pods having no anthracnose or blight spots. These should be shelled by hand or with a flail, and the seed afterward sorted over to remove all discolored, impure, undersized, shriveled, or broken beans. The amount of seed to be selected in this way will depend on the amount needed for planting the main field. If 40 bushels of seed are required for planting the main field and 20 bushels an acre can be

expected from the seed plot, then enough seed must be selected from clean pods to plant two acres.

When the main field contains 200 acres or more, the size of a plot necessary to produce sufficient seed for the main field will be so large that

FIG. 19. A HILL OF WAX BEANS FROM HEALTHY SEED
The pods are entirely free from anthracnose

it will be difficult to obtain by pod selection enough seed to plant it. In such a case it is desirable to maintain an increase plot in addition to a small seed plot. The seed plot would be used to provide clean seed for the increase plot, which in turn would produce sufficient seed for the

main field. This plan would require two years to get seed for the main field, but would afterward permit an economy of time and effort.

2. Location of the seed plot at a considerable distance, preferably 40 rods or more, from other bean fields or garden patches containing beans. If an increase plot is used, it should be located at some distance from the seed plot and also at some distance from the main field. This is to prevent, as far as possible, the transfer of spores of the causal fungus from infected plants to plants in the seed plot. The shorter the distance between the seed plot and beans growing elsewhere, other things being equal, the greater is the chance that the beans in the seed plot will become inoculated.

3. Location of the seed plot and the bean field on soil on which beans were not produced the preceding year.

4. Cultivation of the seed plot before the cultivation of other beans when the same tool is used for both; or, better, reservation for the seed plot of a cultivator not used in other bean fields.

5. The precaution of not visiting the seed plot when vines or soil are wet. This precaution should apply to all bean fields. Care should be taken, even when the vines are dry, not to go directly into the seed plot from other bean fields.

6. Prompt removal and destruction of any plants in the seed plot found to be affected with anthracnose.

7. Application of bordeaux mixture to the plants in the seed plot several times during the season, in order to prevent infection from spores that may be carried there.

8. Selection, before the beans are harvested, of clean and otherwise desirable pods from the seed plot or other fields, in order to obtain healthy seed for planting the succeeding year's seed plot.

9. Careful harvesting of the bean plants in the seed plot and their storage in a place separate from other bean vines.

10. The threshing of the beans with a flail or in other ways so that a mixture with other bean seed cannot take place.

11. Storage of the seed in a cool, dry place until planting time the succeeding year.

12. Careful hand-picking of this seed for the increase plot or the main field in order to remove all discolored or otherwise unsatisfactory seed.

This method of controlling anthracnose in the main field will cost less than spraying five times, and is more certain of success. Much of the procedure costs nothing, but merely requires not doing certain things. The labor involved in growing a 40-acre field of beans by this method, above that ordinarily required for growing such a field, consists in selecting sufficient seed for a seed plot, in spraying the vines in this plot, in removing affected plants from it when present, in the separate harvesting and threshing of the crop, and in the careful hand-picking of the seed from it. Other work done in connection with the seed plot would have been required had it been a part of the main field.

If home-grown seed is as good as or superior to that purchased elsewhere, then growers of a large acreage of beans who have felt the loss from anthracnose, or seed dealers who are desirous of obtaining the best possible seed for their territory, should give consideration to this method. It is not to be expected that many farmers will adopt such a method, because of the detail required in order to insure success. It should be pointed out here that this method cannot be depended upon absolutely to control bacterial blight. Burkholder (1921:67) states that as a result of systemic infection of the bean plant the seeds may become infected without the pods around them showing any evidence of blight.

Procuring seed from localities where anthracnose does not occur

Observations were made for two seasons (1908 and 1909) of fields planted with Colorado-grown and eastern-grown Refugee Wax bean seed. There was no anthracnose but considerable blight present in the field planted with the western seed, while anthracnose was present to some extent in the field planted with the eastern seed. The seed procured from Colorado the second year was dry and split easily, and besides it germinated poorly, and so the yield was lower than that from the eastern seed. Edgerton (1910:50) has planted Colorado seed in Louisiana and has found it freer from anthracnose than most other seed, though much more severely affected with bacterial blight. Muncie (1917:41) reports trials in Michigan of seed grown for one year in the States of Washington, Idaho, and California. There was a little anthracnose in the seed returned from Washington but none in that from the other States. Idaho-grown seed gave very satisfactory results the first year but poor results the second year, largely because the seed was immature due to an early frost.

California-grown Early Wonder seed gave excellent results, and the plants ripened two weeks earlier in Michigan than did plants of the same variety from seed grown in Idaho and from seed grown in Michigan. Muncie believes that carefully selected seed sent to southern California to be grown for one year for seed purposes, will furnish a supply of seed year after year that will be superior to Michigan-grown seed.

Edgerton (1910:28–37) states that at the high summer temperatures in Louisiana, bean anthracnose does not develop even when spotted seed is planted; and later he suggests (Edgerton and Moreland, 1913:17) that Louisiana truckers grow their own bean seed during the summer as a second crop and thus secure seed freer from disease than that purchased from the North.

The question whether eastern growers would have better success in buying western seed than by the use of eastern-grown seed is still unanswered. It must be considered from other standpoints as well as from that of controlling anthracnose. It is true that this disease does not occur as commonly or cause as much damage in the West as in the East. It was, however, rather prevalent in Colorado in 1916 and 1917, and to an extent sufficient to cause some spotting of the seed. Bacterial blight occurs rather commonly in the West, so that one cannot depend on western seed being free from this disease. Nevertheless, eastern seedsmen have found that they can depend upon getting good seed from the West oftener than from the East, and the bean-seed-growing industry has developed rapidly in Colorado and Idaho in recent years. Most of the seed beans grown are garden and canning varieties, which command a much higher price in the East than the ordinary field sorts.

Avoiding conditions favorable for the dissemination and growth of the fungus

If it becomes necessary to plant seed having a small percentage of anthracnose infection, or if the disease appears in the field from an outside source of inoculum, or even when clean seed is planted, it is advisable to avoid as far as is practicable those conditions which favor the spread of the pathogene. Healthy plants have been grown from clean seed in experimental plots in the same field with plants that have become badly diseased from artificial inoculation with the anthracnose fungus. It has been observed also in a large number of instances that plants in hills next to inoculated plants often did not become infected although

the weather was favorable for infection to take place. The disease did not spread because certain conditions favorable for it were not allowed to exist. Some of the precautions to be taken are considered in the following pages.

Manner of planting

Beans planted so close together that they form a dense mat of vines favor the spread of the disease. The vines obstruct cultivation and do not allow either the wind or the sunshine to dry out the moisture beneath them. Spores of the pathogene, if present, are transferred from one plant to others in contact, and are able under the moist conditions to germinate and penetrate the tissues of the host without difficulty.

The different varieties vary so much in their habit of growth and in the size of their seed that it is impossible to give a general recommendation for planting. Halsted (Halsted and Kelsey, 1895:28, and Halsted, 1897: 290) planted seed from 3 to 24 inches apart in rows 20 inches apart. There was a considerable decline in the proportion of spotted pods and also in the total yield of pods as the distance between the plants was increased. Halsey concludes that $4\frac{1}{2}$ inches is the most satisfactory distance for Golden Wax beans. Ferris (1909:8) recommends, in addition to selecting clean seed, planting the beans in bunches in the row far enough apart so that the clusters do not touch one another. Edgerton (1909:5) finds three beans to the hill, and the hills 18 inches apart, a very satisfactory planting distance for beans grown in Louisiana. Fischer (1919) says that Riehm suggests planting in hills 50 by 50 centimeters apart instead of in drills, in order to permit good air drainage. Von Diakonoff (1909) suggests planting the rows parallel to the direction of the prevailing winds in order that the plants may be well aërated.

Anthracnose will not spread through a field of beans planted in hills as rapidly as it will through one planted in drills, because the vines in one hill are somewhat isolated from vines in other hills for a considerable part of the season, whereas in drills there is a continuous row of plants in contact with one another, and anthracnose starting at any point in the row would, under favorable conditions, spread the entire length. To secure maximum protection by hill planting, the hills should be far enough apart each way so that the vines of one hill will not come in contact with vines of other hills; and this distance will vary with different

varieties. Of course the yield in such a case will be reduced below that obtained when a greater amount of seed is used, but not proportionately. It is impracticable, however, to plant hills at a distance sufficient to keep the vines of one hill from touching those of others during the latter part of the season. Just what distance apart the hills of any variety should be planted in order to secure a satisfactory yield and protection from infection has not been determined. Whatever has been said on this subject should be considered also in the light of present knowledge concerning the possibility of spore dissemination by spattering.

Good land drainage

The relation of drainage to bean anthracnose is obvious. Poorly drained soil is cold, and bean seed planted in such soil starts slowly or not at all. If the seed is diseased, the fungus develops rapidly and usually destroys the seedling before it appears above ground. During a wet season poorly drained soil tends to produce a moist condition about the base of the plants, which should be avoided. Galloway (1889) notes that the disease is worse on moist soil. Cobb (1894:383) and Querner (1908), in recommending control measures for the disease, suggest draining the land, and others suggest not choosing low, damp ground.

Removal of affected seedlings

Affected seedlings serve as a source of infection to healthy plants in the field and the garden. An early removal of them would aid in lessening the amount of disease should favorable weather for infection follow. The practice of removing affected plants was early recommended. Berkeley (1880) suggests that diseased plants be pulled and burned, and many other writers on the subject have recommended this. Whetzel (1908:433), however, has pointed out that this method is absolutely impracticable except in short garden rows. It is, of course, out of the question to attempt to remove affected seedlings from a field. However, in the seed plot and in the garden it is worth while to remove and destroy such plants, as is explained later. If the weather remains dry following the appearance of the seedling, the diseased cotyledons will drop off before further infection of the seedling takes place, as already noted (page 161). In such a case the field would be as free from disease as though every diseased seedling had been removed. Appel (1916) has

observed that hilling young plants tends to prevent the spread of the disease by covering the lesions at the base of the stem, thus hindering the spores from escaping. The small lesions heal afterward, and, while the larger ones may develop and rot the plant, the spores produced are not able to be disseminated. Edgerton (1909:5) suggests that danger of the disease's spreading from affected seedlings may be lessened if the field is not entered until the cotyledons have dropped off.

Leaving the plants untouched while wet

As has been noted (page 176), a diseased plant may exist in a field of beans without the disease spreading materially to other plants. If, however, when the plants are wet, some agent passing through the field comes in contact with the diseased vine, spores are likely to be distributed to plants beyond. A very active agent in distributing spores is a horse and cultivator, or, even more so, a person picking beans. Growers of a large acreage like to start work in the fields early, and yet there are many mornings during the growing season when the dew remains on the plants until after nine o'clock. It is very important that operations in the bean field should be postponed until the vines are dry. The observance of this simple precaution will do much toward preventing a general infection of the field.

Destroying diseased vines in the fall

Since the fungus lives over winter on the old pods and vines, these may serve as a source of infection to young beans growing near them the following spring. Galloway (1889) recommends the burning of all diseased vines and pods. Both Harvey (1894) and Cobb (1894:383) believe it advisable to remove and destroy all diseased vines after harvest if the same land is to be used for beans the following year. Whetzel (1906:209) states that diseased pods and stalks should be removed from the field. The old vines and pods are not so often a source of inoculum as are the affected seeds, and yet it is unwise to disregard them altogether. One should not go to a considerable expense to remove and destroy old affected vines from the field, but should prevent their coming into contact with the new crop as far as it is practicable to do so. A rotation of the bean crop, and the application of manure containing bean refuse to other than the current or the following year's bean field, are helpful measures.

Planting at a time of the year when anthracnose is least likely to be present

Corbett (1907) suggests late planting as a possible means of avoiding the disease. This may do very well where the growing season is long, but in New York State the varieties usually planted require practically all the growing season to properly mature their pods. Since the months of July and August are drier on the average than the other months of the growing season, early-maturing varieties planted at the beginning of July might be less likely to be affected with anthracnose than if planted earlier, as the disease would not have as good an opportunity to develop from affected seeds. There are so many other factors of importance in deciding the time of planting, however, that this one of preventing anthracnose can be given little consideration.

Planting early-maturing varieties

There are years when anthracnose does not become prevalent until the fall rains come on, so that an early-maturing variety would escape infection. A variety of white pea bean known as Early Wonder is recommended by Muncie (1916) to Michigan growers because it ripens from ten to fourteen days earlier than other varieties of this kind, and thus matures before diseases have made serious invasion into the tissue of the pod, with consequent spotting of seed. This bean does not ripen appreciably earlier in New York than does the ordinary Navy Pea.

Spraying

It is interesting to note that even before the discovery of bordeaux mixture, the application of a fungicide to bean pods for the control of anthracnose had been made. Frank (1883 b: 523) found that flowers of sulfur greatly decreases the number of cases of infection but provides no real security against the disease. Scribner (1888: 364) states that under some circumstances applications of solutions of sulfate of iron or of copper may be made, but their use on the fruit cannot be generally recommended because of their poisonous character. He suggests the use of liver of sulfur, one ounce to five gallons of water. Galloway (1889) recommends a very early application of hyposulfite of soda, one ounce to one gallon of water, or of potassium sulfide, one-fourth ounce to one gallon of water. Two subsequent sprayings should be made after the pods are from one-half to two-thirds developed.

Five years after the introduction of bordeaux mixture into the United States, several investigators recommended its use for the control of bean anthracnose. Beach (1892:314–317, 326) experimented with cupric borate, cupric polysulfide, and bordeaux mixture. The last-named was much superior to the others and increased the yield to nearly double that of unsprayed plants. Beach emphasized the importance of spraying thoroughly and of using a nozzle that would produce a misty spray. He believed that the addition to the mixture of enough soap to make suds would cause the mixture to form a thin film over the leaves instead of minute drops. McCarthy (1892:14) recommends either an iron sulfate or a potassium sulfide solution with lime, to which molasses or glue is added as a sticker. He recommends also, as a substitute for the spray solutions, a dust mixture composed either of sulfur flour or precipitated copper carbonate diluted with some dry powdered material, as air-slaked lime or wheat flour. He believes that the application should be made as soon as the flowers have withered if there is any disease in the neighborhood. Halsted (1895 [Halsted and Kelsey] to 1901) carried on spraying experiments with beans for seven years. He used a large number of fungicides, including lime-bordeaux of various strengths, soda-bordeaux, potash-bordeaux, ammoniacal copper carbonate, eau céleste, creolin, and potassium sulfide. Soap also was used in combination with copper sulfate and with eau céleste. Halsted found that there was little difference between the regular bordeaux and the soda-bordeaux in their effects, but the other fungicides proved inferior and creolin was practically worthless. When anthracnose and blight were prevalent they were reduced materially, in most cases, by spraying with bordeaux. With the two successive crops of 1896 (Halsted, 1897:330) and the two of 1897 (Halsted, 1898:310, 312), the check row yielded more beans than did the sprayed rows. During the dry seasons of the year 1900 (Halsted, 1901 b:420, 421), little or no success was obtained from spraying. Whetzel (1906:208) relates an instance in which a single spraying reduced the amount of anthracnose 20 per cent. Blin (1906) obtained relatively good results in France during 1901 and 1902 from spraying with bordeaux. Von Diakonoff (1909) advises bordeaux or a copper-sugar-lime mixture.

County agricultural agents have occasionally reported instances in which spraying has given good results in preventing the disease. Nearly all the spray calendars and bulletins on the subject issued by the various

experiment stations include spraying with bordeaux mixture in their recommendations for control of bean anthracnose. In later years, instances have occurred in which bordeaux was reported as not successful in controlling the disease although the vines were well sprayed.

Fairchild (1894), White (1906:95), Corbett (1907), and Whetzel (1908: 433) question the practicability of spraying beans generally, although granting that there may be circumstances under which it could be recommended. Whetzel has succeeded, however, in controlling the disease on a few rows by thoroughly and properly applying the mixture with a hand machine. He says that the field machines are not constructed so that the mixture can be applied as thoroughly and effectively as by hand. He believes that until a machine is put on the market capable of delivering a spray that will cover the stems and the pods at any stage in the growth of the plant, little or no results can be expected from spraying, and even then the practice will be very expensive because of the machinery, chemicals, and labor involved. Hollman (1915) sprayed plants grown from affected seed with 1-per-cent bordeaux mixture without much success, but he advises its use as a protective measure. Fischer (1919:249) tells of Schander and Krause's experiments at Bromberg, where a 1- or 2-per-cent soda-bordeaux and a 1- or 2-per-cent lime-bordeaux were used. The soda-bordeaux killed the plants and the lime-bordeaux injured them, at least when the solution contained just enough lime to neutralize the copper sulfate solution. Later experiments with 1-per-cent bordeaux, even when seed from healthy pods sorted from diseased plants was used, reduced only slightly the number of affected pods and did not prevent the disease from appearing on the leaves and stems.

The writer conducted spraying experiments during the years 1908 and 1909 in large fields of canning beans at Oneida, New York, in cooperation with the Burt Olney Canning Company, in small experimental plots at Oneida during 1908, 1909, and 1910, and at Ithaca, New York, for six years after 1910. The field sprayings were conducted on 200 acres or more of beans. These were sprayed five times during the growing season, at intervals of about ten days, the applications beginning when the plants were just out of the ground and continuing until after picking had begun. Bordeaux mixture (4–4–50) was used on part of each field and lime-sulfur (1–50) on another part, the two sprayed areas being separated by fifteen unsprayed rows. With the varieties of beans grown, Refugee Wax and

Refugee Green Pod, the pods and the undersides of the leaves, which are the particular points of attack, are so protected by their bushy growth that it is very difficult to apply the mixture thoroughly to these places with the ordinary field sprayer. A Niagara gas sprayer was used and the mixture was delivered at 100 pounds pressure from near the ground to the sides of the plant (fig. 20). Two and sometimes three machines were kept busy during the spraying season. In 1908 the company expended $1000 for bean spraying alone, and in 1909 the expenditure was $1250. Each application cost about $1 an acre. Thus the spraying

FIG. 20. PLATFORM AND APPARATUS FOR PREPARING BORDEAUX MIXTURE IN LARGE QUANTITIES, AND SPRAYING MACHINE DEVISED ESPECIALLY FOR SPRAYING BEANS

question was of sufficient importance to the officials of the company for them to wish to have its value demonstrated, and this in spite of the fact that they had been spraying for the past seven years.

A calculation of the yield, and of the amount of anthracnose and blight, for the three center unsprayed check rows and for the three bordeaux-sprayed rows adjoining, was made at each picking of every field. A calculation of the yield of plants sprayed with lime-sulfur was made from only a few fields.

The amount of anthracnose and of blight during the two years was negligible. The difference in yield between sprayed and unsprayed rows was slight, being one year in favor of the sprayed rows and the following

year in favor of the unsprayed, and in both cases being well within the range of experimental error. The company has since discontinued spraying beans.

During the eight years since 1908 a few rows of beans have been thoroughly sprayed with bordeaux, and a few with lime-sulfur, a hand machine being used. From four to six thorough applications were made throughout the season, beginning soon after the plants appeared and continuing until the pods were about two-thirds grown. The first year neither anthracnose nor blight appeared to any appreciable extent, even on the check rows. In 1909 no anthracnose was present, but the blight appeared to be controlled somewhat by the application of the spray. With one variety, Refugee Green Pod, there was no blight on the sprayed rows while in the unsprayed rows 3 per cent of the pods were spotted with blight. On the Red Marrows that were sprayed 2 per cent of the pods were spotted with blight, while the unsprayed rows had 11 per cent of spotted pods.

In 1910 both anthracnose and blight were again negligible. In 1911, one-third of each of six rows was planted on June 22 to seed of several varieties mixed together, all badly spotted with anthracnose. Mixed varieties were used because it was not possible to obtain a sufficient quantity of affected seed of one variety. The remaining two-thirds of the six rows were planted at the same time to seed selected from clean pods, three rows to Red Marrow and three to Navy Pea. The first and fourth rows were sprayed with bordeaux, the second and fifth rows were not sprayed, and the third and sixth rows were sprayed with lime-sulfur. Powdered arsenate of lead at the rate of 2 pounds to 50 gallons was added to both the bordeaux and the lime-sulfur, in the hope of killing insects that might be instrumental in carrying the blight organism. Five applications were made during the season, on June 13, July 1, 14, and 25, and August 9. One-half of the plants in that part of the plot farthest from the end planted to spotted seed were inoculated with a suspension of spores of two strains of *Colletotrichum lindemuthianum* which had proved virulent on the two varieties. This left one-half of the plants from clean seed as a middle third of each row uninoculated with the fungus in any way except with spores that might be carried to them. Two inoculations were made, one on July 17 when one-half of the plants set aside for this purpose were inoculated, and the other on August 22, when the remainder

were inoculated. These inoculations were made at times when the weather promised exceptionally favorable conditions for infection, and it proved to be so in each case. The plan of the experiment may be outlined as follows:

Applications	Clean seed		Spotted seed, plants not inoculated artifically
	Plants inoculated artificially	Plants not inoculated artificially	
Bordeaux I.....	Red Marrow.....	Red Marrow.....	Mixed varieties
Not sprayed I.....	Red Marrow.....	Red Marrow.....	Mixed varieties
Lime-sulfur I.....	Red Marrow.....	Red Marrow.....	Mixed varieties
Bordeaux II.....	Navy Pea.....	Navy Pea.....	Mixed varieties
Not sprayed II.....	Navy Pea.....	Navy Pea.....	Mixed varieties
Lime-sulfur II.....	Navy Pea.....	Navy Pea.....	Mixed varieties

The spotted seed was largely of the wax type, and the pods were picked when a majority were of marketable size as string beans. The results from this experiment are given in table 7. The healthy pods, after being sorted out, were left in a basket for three days. They were then sorted again and the percentage of pods that had spotted in the meantime was

TABLE 7. YIELD, AND PERCENTAGE OF PODS SPOTTED WITH ANTHRACNOSE AND BLIGHT, FROM SPRAYED AND FROM UNSPRAYED ROWS OF SNAP BEANS GROWN FROM SEED BADLY SPOTTED WITH ANTHRACNOSE, IN 1911

Treatment	Date of picking	Number of plants in row	Number of healthy pods	Pods spotted with anthracnose (per cent)	Pods spotted with blight (per cent)	Additional pods spotted with anthracnose after being picked three days (per cent)
Bordeaux I.....	August 13..	62	307	0.6	1.2	0.3
Check I.....	August 13..	71	663	1.7	6.7	20.0
Lime-sulfur I.....	August 13..	62	380	1.8	12.8	0.0
Bordeaux II.....	August 17..	71	722	4.0	0.1	3.3
Check II.....	August 17..	70	557	18.8	4.5	10.7
Lime-sulfur II.....	August 17..	82	592	2.0	1.5	0.5

determined. No importance is attributed to the comparative yield in number of pods given in table 7, as the seed was mixed and more plants of a prolific nature may have been present in one row than in another.

It is seen from table 7 that there was a decided control of the disease by spraying with either bordeaux or lime-sulfur. The control is especially noticeable on pods three days after picking.

The results with field beans grown from healthy seed are given in table 8. It is seen from this table that spraying the vines with either bordeaux or lime-sulfur materially reduced the percentage of spotted pods due to anthracnose. The spraying does not appear to have controlled the blight.

The pods sprayed with bordeaux in the above experiments were decidedly discolored by the precipitate from the mixture. Fawcett (1907) points out that this may be avoided by making the last application with ammoniacal copper carbonate, which leaves no stain. The pods sprayed with lime-sulfur showed no evidence of stain at picking time.

In 1912 complete results from spraying were obtained from only a small plot, two-thirds of which consisted of Red Marrows planted with seed from clean pods while the other third of each row was planted with spotted seed of mixed varieties. The planting was done on June 13, and applications of fungicides were made on July 7, 17, and 26, and August 6. Bordeaux (4–4–50) and lime-sulfur (32° Baumé, 1–50) were the fungicides used. The results are given in table 9. From this table it is seen that no control of anthracnose was obtained from spraying, and that seeds from clean pods were nearly as badly affected as those from spotted seed. Earlier in the season (July 26), however, the plants from clean seed had shown practically no infection, but infection was common on the plants from spotted seed. Cool, rainy weather during August brought about abundant infection from numerous sources.

In 1913 spraying was done on seven varieties planted in eleven plots 50 feet long. Plots 1, 2, and 3 were planted with seed a small percentage of which was spotted with anthracnose; plots 4, 5, 6, 7, 8, and 9 with seed a large percentage of which was similarly spotted; and plots 10 and 11 with seed from selected clean pods. The planting was done on June 29. The Red Valentine and Challenge Black Wax beans did not germinate well and were replanted on July 12. Applications of fungicides were made on July 16 and 26, and August 6 and 16. The Navy Pea and Red Kidney

TABLE 8. YIELD, AND PERCENTAGE OF PODS SPOTTED WITH ANTHRACNOSE AND BLIGHT, FROM SPRAYED AND FROM UNSPRAYED ROWS OF FIELD BEANS GROWN FROM SELECTED HEALTHY SEED, IN 1911

	Variety	Treatment	Number of plants	Yield of dry pods (grams)	Yield of seed (grams)	Pods spotted with anthracnose (per cent)	Pods spotted with blight (per cent)	Clean pods (per cent)	Spotted seed (per cent)
Not inoculated artificially	Red Marrow	Bordeaux.....	52	1,255	806	25.0	6.5	68.5	0.0
		Check.....	58	1,335	947	76.0	0.0	24.0	18.0
		Lime-sulfur...	56	1,045	765	20.0	3.5	76.5	10.0
	Navy Pea	Bordeaux.....	49	936	704	0.0	5.0	95.0	0.0
		Check.....	47	935	715	36.0	11.0	53.0	10.0
		Lime-sulfur...	48	1,115	850	12.0	14.0	74.0	1.0
Inoculated artificially twice during season	Red Marrow	Bordeaux.....	114	2,525	1,830	33.0	5.3	61.4	0.0
		Check.....	118	2,055	1,455	82.0	1.0	17.0	21.0
		Lime-sulfur...	118	2,010	1,452	27.5	5.5	67.0	17.0
	Navy Pea	Bordeaux.....	92	1,575	1,220	4.0	5.5	90.5	1.0
		Check.....	90	1,610	1,215	49.0	4.5	46.5	10.0
		Lime-sulfur...	92	1,675	1,275	24.0	5.0	71.0	3.5

beans, since they would mature later, were given another application on September 8. Bordeaux (5–5–50), Pyrox (1 pound to 5 gallons of water, as recommended on the label), and lime-sulfur (32° Baumé, 1–50), were

TABLE 9. YIELD, AND NUMBER AND PERCENTAGE OF RED MARROW BEAN PODS SPOTTED WITH ANTHRACNOSE, FROM SPRAYED AND FROM UNSPRAYED ROWS IN 1912

Seed planted	Treatment	Number of pods	Pods affected with anthracnose	
			Number	Per cent
Clean seed	Bordeaux	2,600	2,450	93
	Check	1,452	1,450	99
	Lime-sulfur	1,983	1,950	98
Spotted seed	Bordeaux	392	392	100
	Check	227	227	100
	Lime-sulfur	295	295	100

the fungicides used. A killing frost occurred on September 15. Only the percentage of pods spotted with anthracnose is given in table 10, showing the results:

TABLE 10. PERCENTAGE OF PODS SPOTTED WITH ANTHRACNOSE IN SPRAYED AND IN UNSPRAYED ROWS, FROM ELEVEN PLOTS CONTAINING SEVEN VARIETIES OF BEANS, IN 1913

Plot	Variety	Treatment			
		Bordeaux	Pyrox	Not sprayed	Lime-sulfur
1	Red Kidney	0.0	0.0	0.0	0.0
2	Crystal Wax	*2.4	*0.2	*1.4	*1.0
3	Red Valentine	0.0	0.6	0.0	0.0
4	Challenge Black Wax	0.2	0.8	57.2	0.8
5	Navy Pea	0.4	0.4	0.4	0.4
6	Red Kidney	4.6	6.2	58.6	17.4
7	Crystal Wax	0.2	7.0	36.4	20.8
8	Golden Wax	0.0	0.0	0.0	0.0
9	Refugee Wax	0.0	0.0	0.0	0.0
10	Red Kidney	0.0	0.0	0.0	0.0
11	Navy Pea	0.0	0.0	0.0	0.0

* The cotyledons showed anthracnose lesions.

The season was dry and anthracnose was not abundant, but the results on plots 4, 6, and 7, the only ones having a considerable amount of anthracnose in the checks, lead to the conclusion that the fungicides were effective in the following order: bordeaux, Pyrox, lime-sulfur, with the latter falling short somewhat.

Spraying was continued during 1914 on Refugee Wax, Davis Wax, Flageolet Wax, an unidentified wax, and Burpee's Stringless Green Pod. Rows 50 feet long of each variety were planted on June 2, on plots situated side by side on the same land that was used for this purpose in 1913 (table 11). The Flageolet Wax contained a large percentage of seed spotted with anthracnose, but the seed of the other varieties included only a small amount of spotted seed. The row of Flageolet Wax had many missing hills. Applications of the fungicides were made on July 2, 15, and 26, and August 9. One row of each variety was sprayed with bordeaux (5–5–50), one row of each, except the unidentified wax, with Pyrox (1 pound to 5 gallons of water), and one row of each except Flageolet Wax and the unidentified wax with Sulfocide, a commercial sulfur solution (1 gallon to 200 gallons of water). The remaining row of each variety was left unsprayed as a check.

In order to insure anthracnose infection, two inoculations with spores of *Colletotrichum lindemuthianum* obtained from cultures were made, one on August 2 and the other on August 16. Favorable weather for infection followed in each case, and the weather at Ithaca during the summer continued favorable for the development of the pathogene. All the varieties matured their pods before frost and a record of healthy and spotted pods was made on October 8 (tables 11 and 12).

This experiment shows that all the spray materials used had value in the control of anthracnose and blight. The plants from spotted seed were badly affected, and the control of the disease by spraying was not so good on them as on plants from clean seed.

In 1915 but one variety, Davis Wax, was used in the spraying experiment. Two rows 50 feet long were planted on June 8, one to be sprayed and one to be left as a check. One-third of each row was planted with seed of this variety spotted with anthracnose, and the other two-thirds with seed from selected clean pods. A thorough natural inoculation took place, and so it was not necessary to inoculate artificially. The beans

appeared on June 16 and applications of a fungicide were made on June 19, July 3, 10, 24, and 30, and August 7. Pyrox (1 pound to 5 gallons of water) was used for the first three applications and bordeaux 5–5–50

TABLE 11. YIELD, AND NUMBER AND PERCENTAGE OF PODS SPOTTED WITH ANTHRACNOSE AND WITH BLIGHT, IN SPRAYED AND IN UNSPRAYED ROWS IN 1914

Variety	Treatment	Total number of pods	Pods spotted with anthracnose		Pods spotted with blight	
			Number	Per cent	Number	Per cent
Refugee Wax	Bordeaux	1,120	3	0.3	5	0.5
	Pyrox	1,134	10	0.9	3	0.3
	Check	1,467	129	8.8	7	0.5
	Sulfocide	1,307	93	7.1	4	3.1
Davis Wax	Bordeaux	612	33	5.4	12	2.0
	Pyrox	475	19	4.0	11	2.3
	Check	344	23	6.6	59	17.2
	Sulfocide	173	10	5.8	27	15.6
Flageolet Wax	Bordeaux	74	6	8.0	5	6.8
	Pyrox	90	23	25.8	3	3.3
	Check	174	151	86.8	4	2.3
Unidentified wax	Bordeaux	506	20	4.0	5	1.0
	Check	252	46	18.3	13	5.2
Burpee's Stringless Green Pod	Bordeaux	776	76	9.8	10	1.3
	Pyrox	670	40	6.0	9	1.3
	Check	641	131	20.3	28	4.3
	Sulfocide	411	55	13.4	27	6.6

TABLE 12. AVERAGE PERCENTAGE OF PODS SPOTTED WITH ANTHRACNOSE AND WITH BLIGHT FROM THE VARIOUS SPRAYED AND UNSPRAYED PLOTS ON THE RESPECTIVE VARIETIES EMPLOYED, IN 1914

Treatment	Anthracnose (per cent)	Blight (per cent)
Bordeaux	5.5	2.3
Pyrox	9.2	1.8
Check	28.2	5.9
Sulfocide	8.8	5.1

for the other three, the change to bordeaux being made because of the injury resulting to the vines from the use of Pyrox; three hills, in fact, were killed, and the others on July 15 looked very straggling from the loss of their lower leaves, so that they presented a much less satisfactory appearance than the unsprayed rows, even though they were but little affected with anthracnose. The results of this experiment are given in table 13:

TABLE 13. YIELD OF DAVIS WAX BEANS, NUMBER AND PERCENTAGE OF PODS AFFECTED WITH ANTHRACNOSE, AND WEIGHT OF GOOD AND OF CULL SEEDS, FROM SPRAYED AND FROM UNSPRAYED ROWS IN 1915

Seed planted		Sprayed	Not sprayed
Spotted seed	Number of plants	26	30
	Number of pods	122	129
	Number of pods affected with anthracnose	43	129
	Per cent of pods affected	35	100
	Weight of good seed (grams)	79	10
	Weight of cull seed (grams)	17	52
Clean seed	Number of plants	66	86
	Number of pods	240	521
	Number of pods affected with anthracnose	22	521
	Per cent of pods affected	9	100
	Weight of good seed (grams)	290	89
	Weight of cull seed (grams)	49	410
Total	Number of plants	92	116
	Number of pods	362	650
	Number of pods affected with anthracnose	65	650
	Per cent of pods affected	18	100
	Weight of good seed (grams)	369	99
	Weight of cull seed (grams)	66	462

This experiment, although not conducted on an extended scale, shows conclusively the control that can be obtained by spraying the plants thoroughly with bordeaux mixture a sufficient number of times during the season to protect them.

Spraying was continued in 1916 on Davis Wax and Refugee Wax beans. Two rows 40 feet long of each variety were planted on June 10; spotted seed was used in one-third of each row, and healthy seed in the remainder. No artificial inoculations were made. One row of each variety was left

unsprayed as a check, and one of each was sprayed with bordeaux mixture (5–5–50) on July 3, 12, and 24, and August 3, 14, and 24. Data obtained at harvest, October 4, are given in table 14:

TABLE 14. YIELD OF DAVIS WAX AND REFUGEE WAX BEANS, AND NUMBER AND PERCENTAGE OF PODS AFFECTED WITH ANTHRACNOSE, FROM SPRAYED AND FROM UNSPRAYED ROWS IN 1916

Variety	Treatment	Number of plants	Total number of pods	Pods affected with anthracnose		Weight of good seed (grams)	Weight of cull seed (grams)
				Number	Per cent		
Davis Wax	Sprayed	59	520	93	18	652	64
	Not sprayed	61	437	184	42	175	93
Refugee Wax	Sprayed	80	770	16	2	370	104
	Not sprayed	74	662	121	18	.....	.....

It seems to the writer, in view of the results of these experiments, that anthracnose and possibly blight may be kept in check by thoroughly spraying the plants with bordeaux mixture, if the operation is begun soon after the plants have appeared above ground and continued at intervals of about ten days until the pods are reaching marketable size. The nature of the growth of the plants determines to a considerable degree whether they may be sprayed well with a spraying machine. Varieties such as those used in the field experiments at Oneida are so bushy that it is very difficult to spray them thoroughly, while such varieties as Crystal Wax, Currie, Davis, Detroit, Double-Barrel, and others, which have a more erect growth, although compact, are less difficult of such treatment.

The field experiments at Oneida show conclusively that it does not pay to spray during a dry season. Spraying experiments conducted on a small scale with hand sprayers have shown that it is possible to control the disease to a considerable extent by this method. Whether the disease can be controlled as well with traction or power machines during epiphytotic years is yet an unsettled question.

In regions where anthracnose usually occurs annually, spraying can probably be used to advantage if the practice is supplemented by the use of clean seed. In New York spraying is not practicable for growers of dry beans, and probably not for growers of canning beans. If the total cost of making five applications is $7.50 an acre, it would be necessary for growers of dry beans to get from spraying an increase of 1.5 bushels an acre each year with beans selling at $5 a bushel in order to balance accounts. A decided increase in yield could be expected in a year when anthracnose was prevalent, but none if the season were dry. If an epiphytotic of the disease occurs in two out of seven years, as was the case from 1908 to 1915, then it would be necessary for the grower to get an increase from spraying of about 5.25 bushels in each of such two years in order to come out even. In order to make spraying pay, he must get a greater increase in yield or the selling price must be greater, and the time spent in spraying must not be at the expense of other farm operations.

Applying a fungicide to picked pods before shipping

Rolfs (1897) recommends the application of a sulfur spray just before packing pods for shipping, in order to kill the spores adhering to the pods. Fawcett (1907) also recommends the application of either potassium sulfide or a soda-sulfur spray. He says the pods should be spread out on the floor and the spraying solution thoroughly applied, the pods being turned over during the operation so that all the surfaces will be covered. The pods should be allowed to dry before being crated. In order to guard further against infection, Kirk (1905) suggests the exclusion of affected pods in packing, and Fulton (1908:12) says that affected pods should not be picked, washed, nor packed with sound ones. Containers should be so devised as to allow good ventilation, and the pods should be stored in as dry and cool places as is possible. Since there will be no anthracnose infection on pods during shipment if the disease is controlled in the field, stress should be placed on such control.

Application of a fungicide to the soil

Halsted (1900 a:380) is the only investigator who has ever recorded the application of any fungicide to the soil in an effort to control bean anthracnose, and in his experiment there was no anthracnose on any of his bean

plants throughout the season although blight was present to some extent. He applied bordeaux mixture to the soil at the rate of 4320 gallons to the acre. In the first crop of the year the blight was reduced one-half on leaves and pods, but in the second crop there was just as much blight on these plants as there was on the check. Moreover, the plants growing on land that had received the application were smaller than those on the untreated soil.

Rotation of crops

The idea that the fungus is able to winter in the soil has led many writers to recommend, among other suggestions, that the grower should not plant beans on land that bore a diseased crop the previous season. Harvey (1894:153) calls attention to this, and in the same year Cobb (1894) advises a change of ground. Halsted (1900 b: 127), after growing beans each year on the same ground for a number of successive years, found that the plants yielded more in the first four years than when grown on new land, but less afterward. Usually a greater number of spotted pods were produced on plants grown year after year on the same land.

Observations were made by the writer on beans grown as the seventh successive crop on the same land. They appeared as thrifty, and yielded as well, as any crop grown on rotated land. Moreover, they were as free from anthracnose and blight as the others, although in fairness it must be said that the summers had been dry for the three years preceding the observations. There is little chance of anthracnose occurring where beans are planted year after year on the same ground, if the vines, when affected, are not returned to this soil. There is greater danger that such a practice will introduce other diseases, especially stem rots, which tend to reduce the yield materially.

Selection of resistant plants

As has been stated earlier in this paper (page 149), no variety of *Phaseolus vulgaris* has been found to be absolutely immune to anthracnose, although a selection of the ordinary Red Kidney has been obtained which has proved to be resistant to such an extent that it will produce a very satisfactory yield in years when the ordinary Red Kidney becomes badly affected, and a Nova Scotia White Marrow has been located that shows considerable resistance in the field although susceptible in the seedling stage when inoculated artificially. Further progress in obtaining resistant

beans with these as a basis for hybridization is being made, the resistance being readily tested by artificial inoculation in the field, the cold frame, or the green-house. Selections can be made of large numbers of individuals by artificially inoculating them while in the seedling stage. Any showing marked resistance can be allowed to mature seed, and further tests can be made with them. Investigators are beginning to realize that the selection of plants resistant to disease is a most practical and satisfactory method of disease control, and even now work of this kind is engaging the attention of phytopathologists to a very marked degree.

As already stated (page 149), there are many varieties of beans which, while susceptible to one strain of the pathogene, are resistant to the other. It has been observed that often only one variety of beans is grown in a given locality; for example, Shepard (1919) reports that in 1918 pea beans constituted 76 per cent of all beans grown in Orleans County and 77 per cent of all grown in Monroe County, while in Yates County only 6 per cent of all beans are pea beans while 30 per cent are White Marrow, 29 per cent are Yellow Eye, and 15 per cent are Red Kidney. It happens that the pea bean referred to is susceptible to strain *alpha* of the pathogene but resistant to strain *beta*, while the other varieties mentioned are susceptible to strain *beta* but resistant to strain *alpha*. It is very likely that in regions where the pea bean is grown, strain *beta* does not exist to any great extent, and the introduction of clean seed of varieties resistant to this strain, even if susceptible to the other, would give crops of these varieties free from anthracnose for a few years. Eventually the *beta* strain would appear, and, its host being prevalent, would develop abundantly in years favorable for it. Similar results could be expected from the introduction of the pea bean, or any other variety resistant to the *beta* strain, into localities where this strain is the only one prevalent. There are other factors, to be sure, which tend to discourage a change in varieties in a given locality, and these have largely operated to prevent such changes.

Consideration of prophylactic measures

Bean anthracnose occurs to a serious extent in New York only during two or more wet seasons in succession, and the losses occasioned at such times are often forgotten by the grower in the dry seasons that intervene. It is a question with him then whether the time and the money needed for

successful control measures would not be lost in carrying them out. At the time when the disease occurs, however, he is willing to do anything to lessen its destructiveness. With bean anthracnose, as with most other plant diseases, control measures to be successful must be given consideration before the disease appears, or, better, before the crop is planted; and whatever measures are decided upon must be carried out completely. Frantic attempts to control the disease after it has appeared are usually a waste of time and money and cannot be generally recommended.

When one considers the various measures suggested for the control of this disease, he must realize that each has disadvantages and that the cost would be greater than the gain were all carried out even though the disease was thereby controlled. Some measures offer a greater promise of success than others. These are here summarized and briefly discussed.

Seed disinfection may prove to be worth while, but more experimental work is necessary before it can be recommended.

The avoidance of conditions favorable to the fungus is a precautionary measure that should receive consideration from all bean growers since it involves little or no expense.

Spraying is not a practicable measure for growers of dry beans in New York, but frequent and thorough applications of bordeaux mixture can be depended on to protect the plants from anthracnose; and such a control measure is practicable when the value of the crop is sufficiently great to warrant the expense involved.

As far as present evidence indicates, the application of a fungicide to the soil is impracticable and ineffective.

Rotation of crops, in itself, will not prevent anthracnose nor reduce the liability of its occurrence to any marked extent; but it is a measure that should receive some consideration, since its practice may serve to keep down the losses occasioned by other diseases.

The disinfection of picked pods need be considered only by growers of snap beans who ship to distant markets. This will not be necessary for growers who are successful in controlling the disease in their fields.

The use of anthracnose-resistant varieties is a satisfactory means of control and should be taken advantage of when possible.

The practice of careful hand-picking in order to remove diseased seed cannot be depended upon as an effective control measure because affected seed will escape the eye of the most practiced observer. However, this

practice will reduce the amount of affected seed planted, and if the seed is picked over at least twice the chances of getting a clean crop will be greatly improved as compared with the use of seed that has not been carefully hand-picked.

SUMMARY

Bean anthracnose is a disease of beans, principally affecting varieties of *Phaseolus vulgaris* L., which was first definitely reported and described in 1878 although it probably existed at a much earlier date. It has since been reported from every continent, and from nearly every country where beans are grown.

The disease has caused very large losses in years favorable for its development. In the eastern part of the United States, epiphytotics have occurred in the years 1906 to 1908 and 1914 to 1917.

All parts of the plant, even the roots, are subject to the disease, but it is most noticeable on the pods, where it forms dark, sunken cankers which subsequently extend to the seed contained within.

The spores germinate readily at room temperatures, within twenty-four hours in nutrient culture media and in bean agar and more slowly in water, the germ tube usually forming an appressorium on contact with a hard substratum.

A moderate growth of mycelium is produced in culture, which becomes dark-colored and forms acervuli from which a flesh-colored mass of spores is exuded. Under favorable conditions spores may be produced after three days growth. Cultures lose their power to produce spores by age or continued exposure to temperatures above the optimum. As the culture dries, setae are produced within and around the acervuli.

The minimum temperature for growth lies between 0° and 4° C., the optimum near 22°, and the maximum between 34° and a few degrees lower.

The fungus after entering the host extends its hyphae horizontally and diagonally into the cells. Browning of the cell contents occurs soon after the attack. The walls collapse and a lesion may be observed, at the earliest, four and one-half days after inoculation.

A stroma is formed at about the time when the cells collapse, and from it arise, in various places, a cluster of conidiophores which push up the epidermis, forming pimples. Spores are produced at the extremity of

the conidiophores, and these spores break through to the surface as a pasty mass. The fungus is capable of living from one season to another, and even for two seasons, in old affected vines and pods, which may serve as a source of inoculum when carried to the field. Spores washed into the soil are not viable to any extent after seven weeks.

The fungus when it invades the seed is able to live in its tissues in a more or less inactive condition for at least two years when the conditions of seed storage are not unfavorable for it.

Plants in the seedling stage and the youngest parts of older plants are the most susceptible to the disease.

There are at least two strains or biologic forms of the fungus. Many varieties of *Phaseolus vulgaris* resistant to the one are susceptible to the other, and vice versa. There are some varieties that are very susceptible to both strains, and at least one that is highly resistant to both. The wax-podded bush beans include a larger percentage susceptible to both strains than are found in other groups of varieties.

Several other species of Phaseolus are susceptible to anthracnose, but in this country, with rare exceptions, the disease is not severe nor often noticeable on such plants.

A few species of the related genera Vigna (cowpea) and Dolichos (kulthi and val bean) have shown some susceptibility in a few cases, but plants of other genera which have been inoculated have shown complete immunity.

Varieties of *Phaseolus vulgaris* are not susceptible to infection by fungi causing anthracnose of other plants, so far as infection experiments on them have been tried.

Selection of seed from clean pods has given a crop free from anthracnose in nearly all cases, and has always given anthracnose-free seedlings in clean soil.

Western-grown bean seed gave crops free from anthracnose but with considerable blight.

Spraying with bordeaux mixture throughout the season has prevented anthracnose to a large extent even in seasons favorable for it. In dry seasons spraying does not increase the yield. Applications of lime-sulfur solution and of two prepared fungicides gave some control, but not as good control as did bordeaux mixture.

The use of resistant varieties gave greatest promise of a satisfactory means of control.

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PLATE I

PATHOLOGICAL ANATOMY OF BEAN ANTHRACNOSE

1, Section across an anthracnose lesion on an immature pod, showing depth of lesion, affected tissues, and spore masses. Drawn with aid of camera lucida. × 25

2, Section across a lesion on pod of Golden Refugee bean, showing an acervulus with spores and several setae. Drawn with aid of camera lucida. × 166

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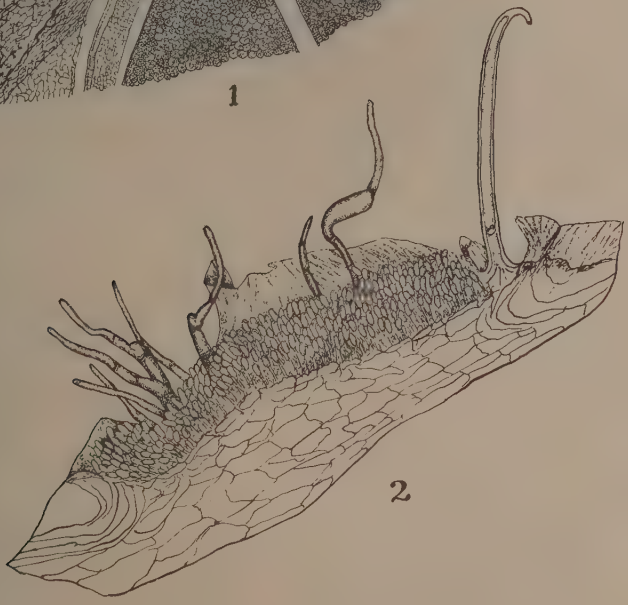

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PLATE II

DEVELOPMENT OF COLLETOTRICHUM LINDEMUTHIANUM WITHIN HOST TISSUE

1, Section across very small, newly formed lesion on Refugee Wax bean pod. The dotted part represents discolored area as seen in the microscope, the mycelium extending beyond this. Spores are being produced in a pocket beneath the cuticle, which is not yet ruptured. × 55

2, Same tissue, higher magnification. The disorganization of subepidermal cells can be noted. × 166

3, A few cells from cross section of an infected wax-bean pod, showing advancing fungous hyphae

4, Section across recently invaded tissue of outer coat of affected pod, showing twelve fungous hyphae penetrating the wall of a cell. × 333

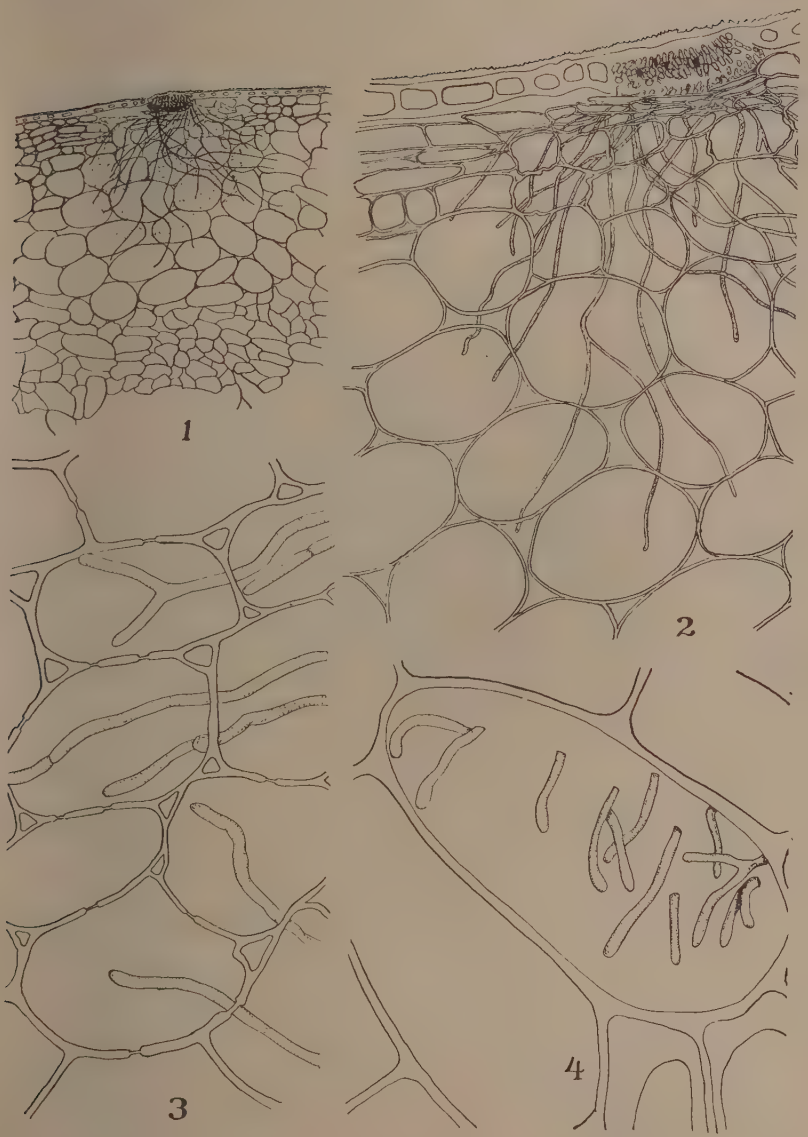
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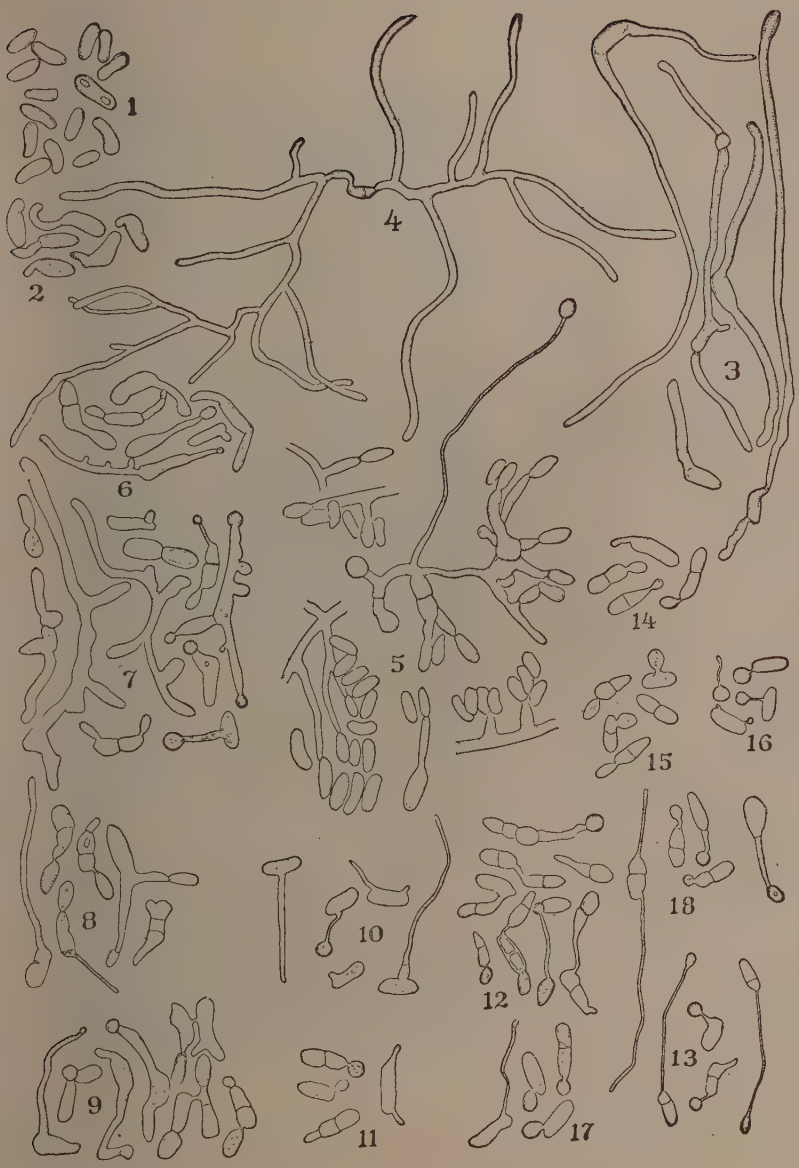
PLATE III

CONIDIA OF COLLETOTRICHUM LINDEMUTHIANUM

(Temperature varied from 20 to 24° C.)

1, Conidia from an acervulus, × 342. 2, Conidia germinating after 9 hours in bean agar, × 339.47. 3, Germination after 20 hours in bean agar, × 347.36. 4, Germination after 54 hours in agar, × 166.73. 5, Spore formation after growth of 4 days in agar, × 347.36. 6, Germination and production of appressoria after 19 hours in sugar solution, × 339.47. 7, After 36 hours in sugar solution, × 347.36. 8, After 66 hours in sugar solution, × 347.36. 9, After 84 hours in sugar solution, × 363.15. 10, After 18 hours in water, × 347.36. 11, After 37 hours in well water, × 363.15. 12, After 65 hours in well water, × 347.36. 13, After 9 days in well water, × 363.15. 14, After 36 hours in distilled water, × 363.15. 15, After 62 hours in distilled water, × 363.15. 16, After 8½ days in distilled water, × 363.15. 17, After 38 hours in rain water, × 363.15. 18, After 66 hours in rain water, × 347.36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ANTHRACNOSE ON BEAN SEEDS

Upper left, Navy Pea; upper right, Red Kidney; lower left, White Marrow; lower right, Brockton

ANTHRACNOSE ON PODS OF WAX AND GREEN-POD BEANS

The acervuli can be seen in the larger lesions

BACTERIAL BLIGHT ON RED KIDNEY BEAN PODS

RUST (UROMYCES APPENDICULATUS,) ON BEAN PODS